2012 :15th SESSION of ESMP

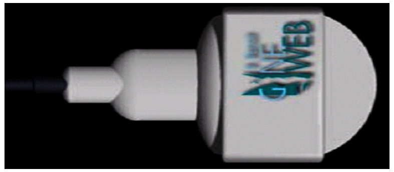
Lecture presented in Archamps (Salève Building) by :

Jean-Martial MARI (INSERM Lyon)

Ultrasound session

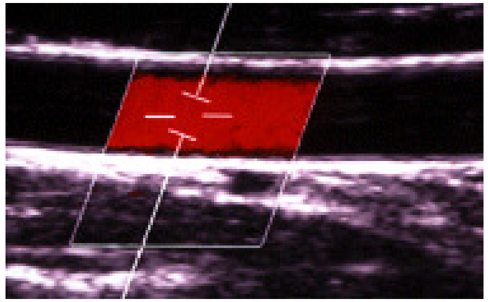
Ultrasound Basic Principles

Jean Martial Mari
Christian Cachard



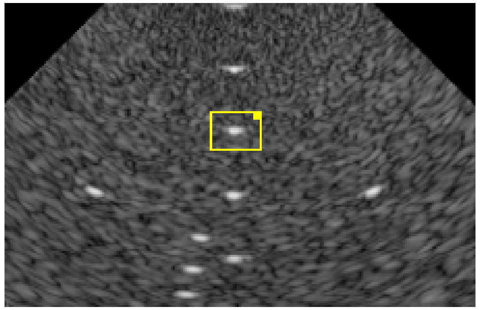
Transducer

Hervé Liebgott



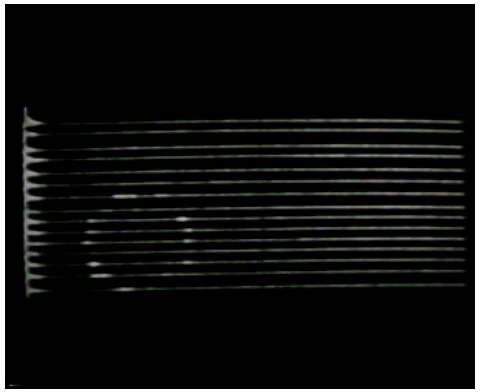
Ultrasonic Doppler Mode

Piero Tortoli



Quality assurance of US equipment

Jean Martial Mari

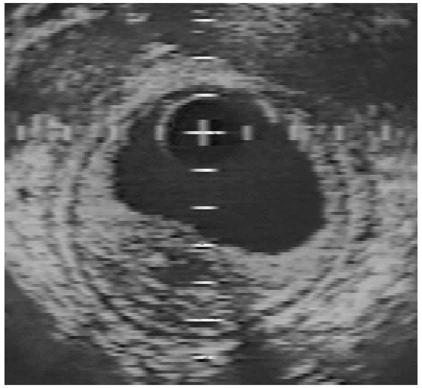


40 years of medical ultrasound

Nico de Jong

Ultrasound session

Specific applications



IntraVascular UltraSound

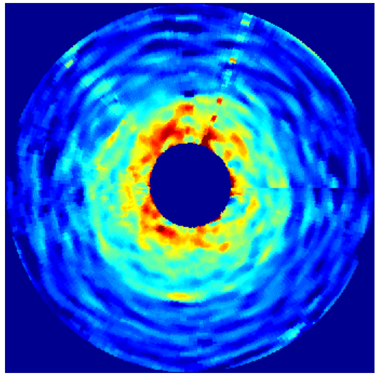
Nico de Jong

Contrast Agent

Nico de Jong

Therapeutic Ultrasound

Jean Martial Mari



Ultrasound Elastography

Jean Martial Mari

Post Image Processing

Hervé Liebgott

Ultrasound session

Diagnosis

Low intensity

Therapeutic

Jean Martial Mari

High intensity

European School for Medical Physics 2012

Basic Principles of Ultrasound

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Teresa Robinson

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Head of the Vascular Studies Unit, United Bristol Healthcare NHS Trust

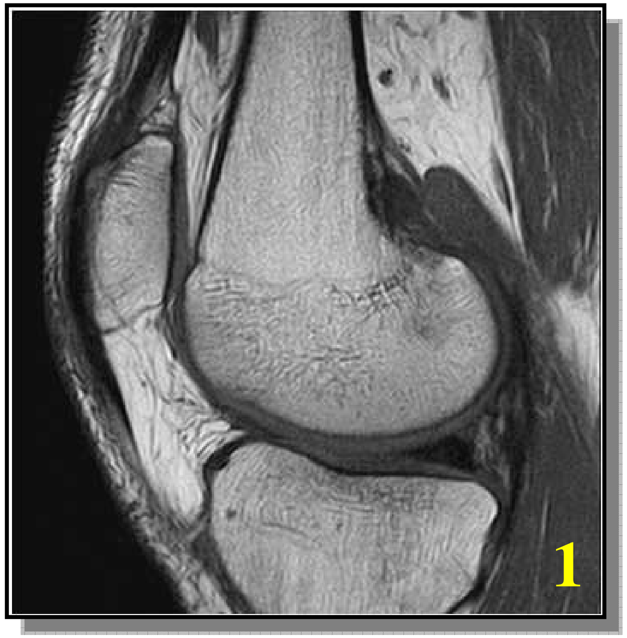
Basic principles of ultrasound

1: Overview and history

2: Sound waves

3: Ultrasound generation

4: Ultrasound in tissue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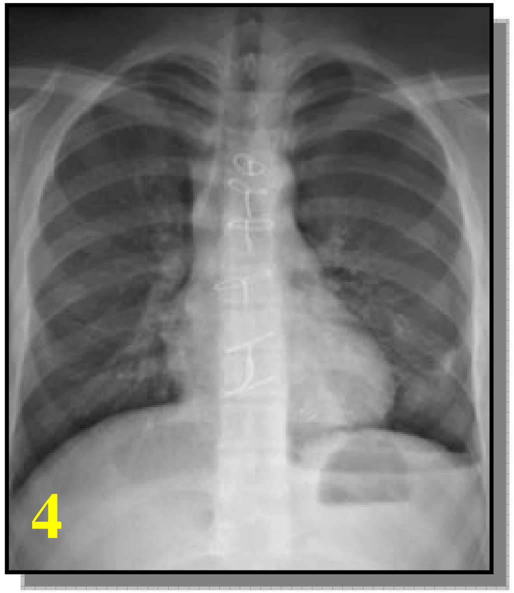
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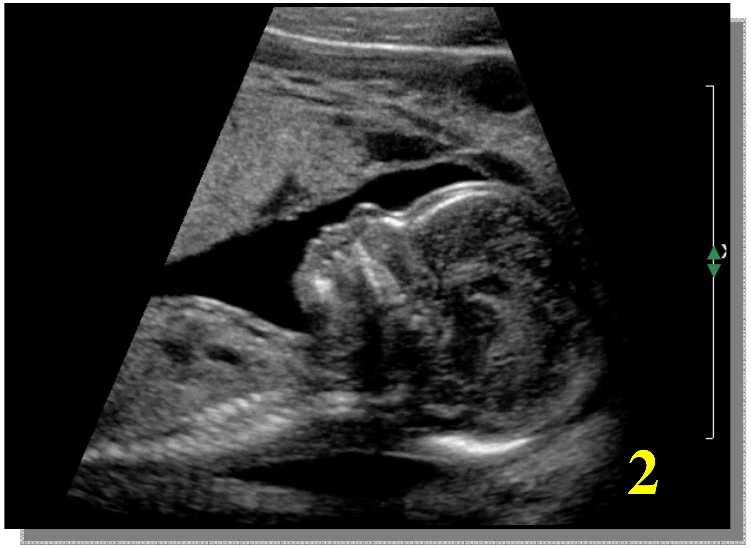
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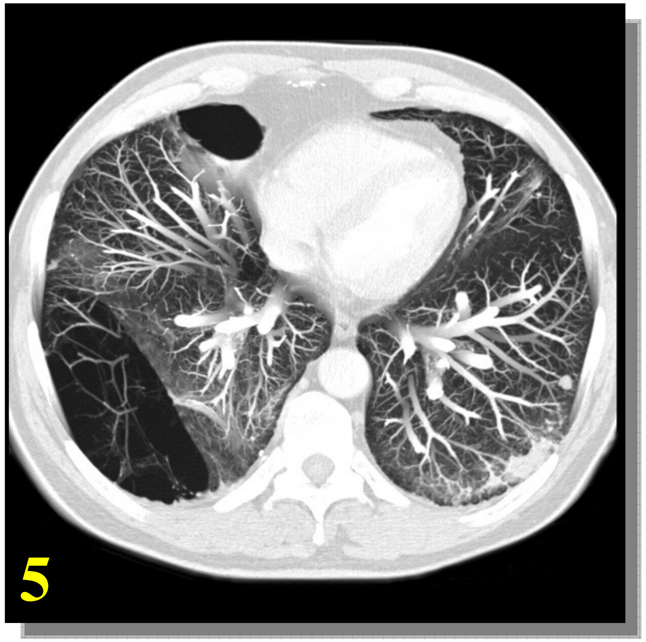
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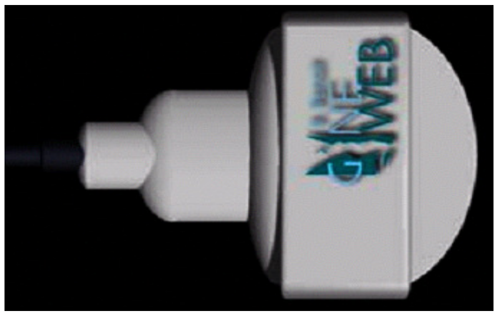
Ultrasound scanning

Scanner



Probe

The place of ultrasound in medical imaging

Public Hospitals in Lyon (2000)

- 4 IRM
- 8 scanners
- 10 angiographic
- 10 PET
- **One hundred ultrasound scanners**

Specific rooms

The place of ultrasound in medical imaging

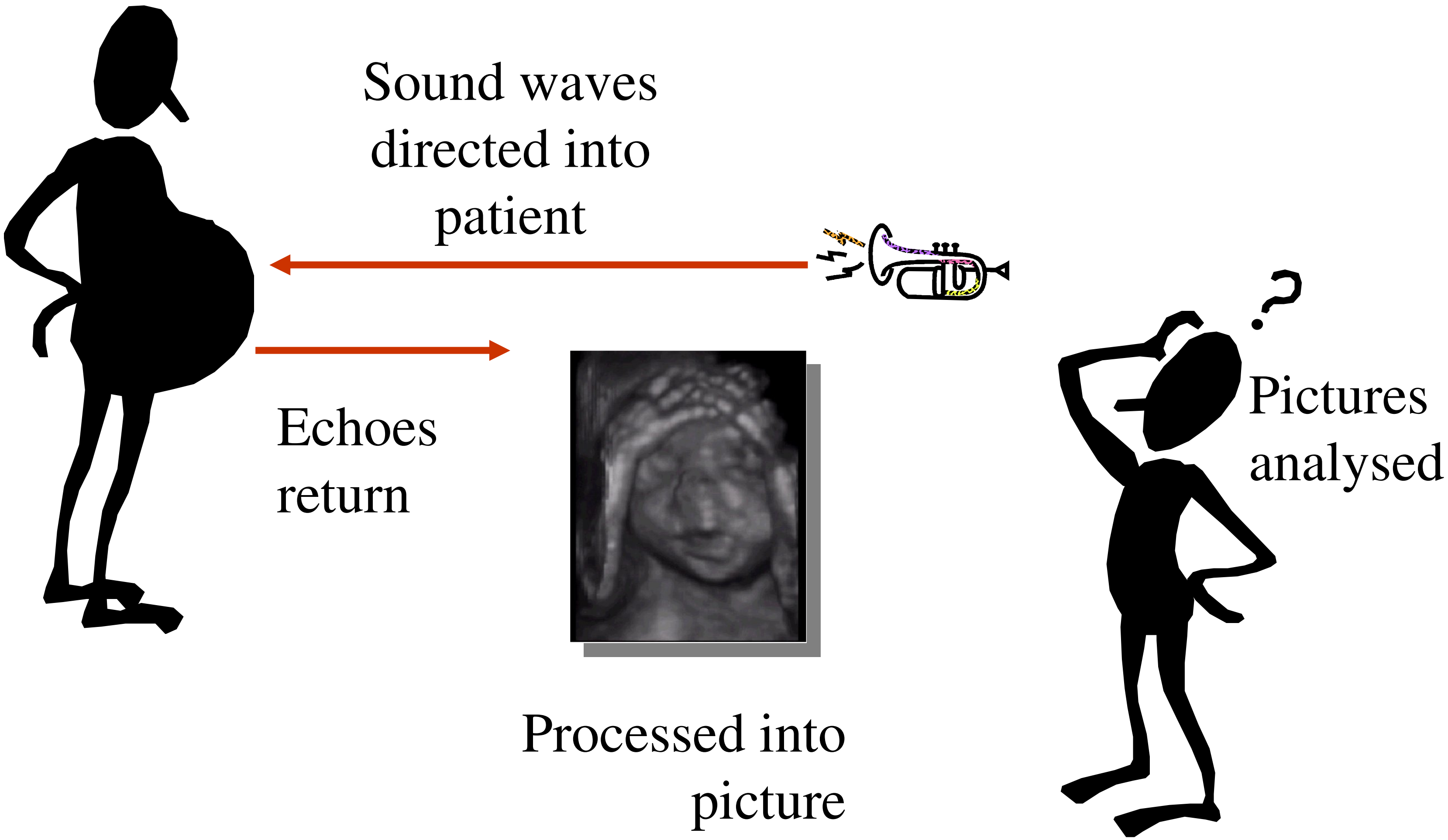
- **real time imaging**

IN LIVE

The place of ultrasound in medical imaging

- Ultrasound has the last ten years been the fastest growing imaging modality for non-invasive medical diagnosis.
- Of all the various kinds of diagnostic produced in the world, one of four is an ultrasound scan.
- Reasons for this are the ability to image soft tissue and blood flow
  - the **real time imaging** capabilities,
  - the **harmlessness** for the patient and the physician (no radiation)
  - the **low cost** of the equipment.
  - **no special building** requirements as for X-ray, Nuclear, and Magnetic Resonance imaging.
- Limitations are that ultrasound imaging cannot be done through bone or air (limitations on chest imaging).

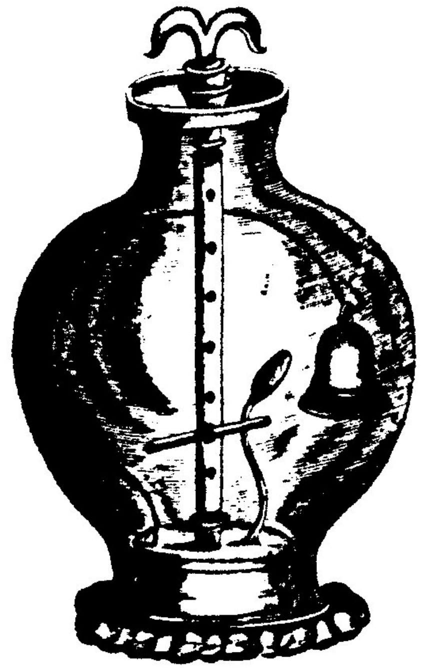
Diagnostic Ultrasound



Mechanical wave

Sound is a mechanical wave

- ➢Created by a vibrating object
- ➢Propagated through a medium



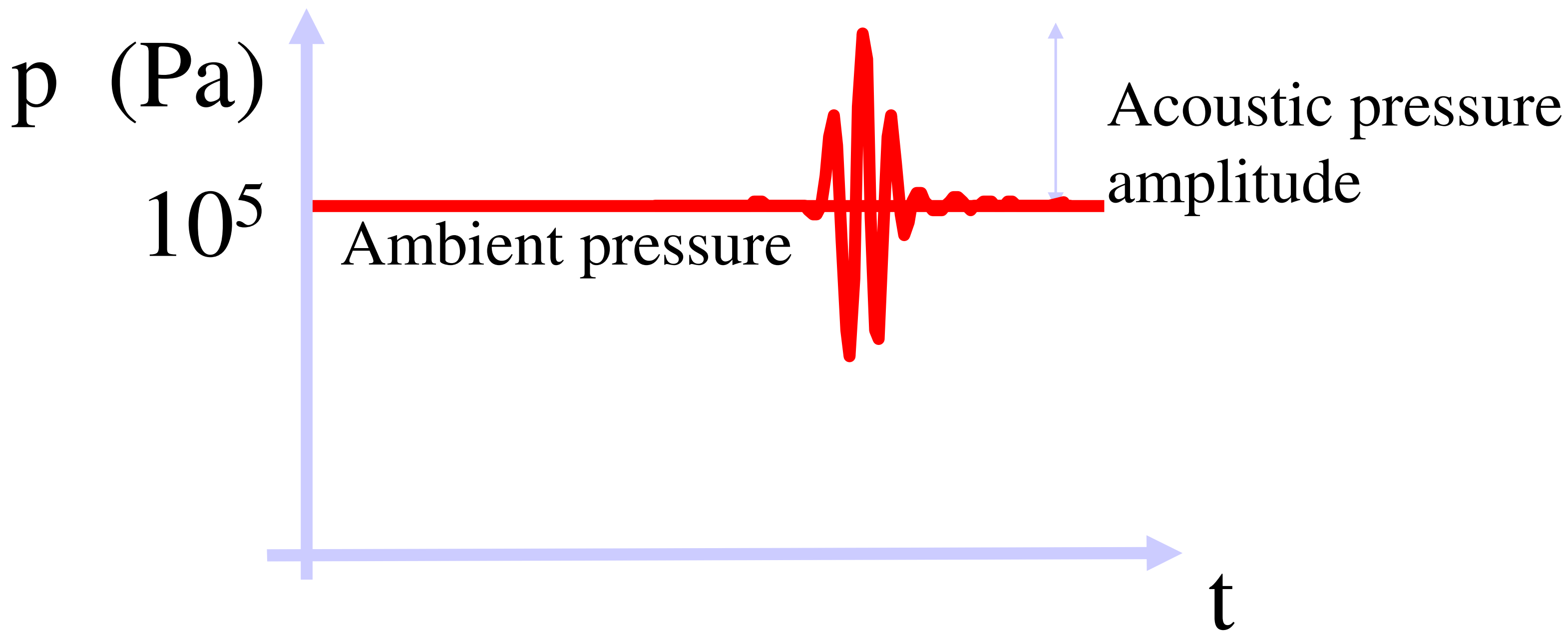
Vacuum chamber

- Ultrasound energy is exactly like sound energy, it is a variation in the pressure within a medium.

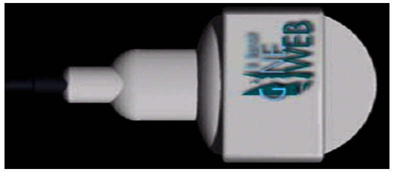
The acoustic pressure

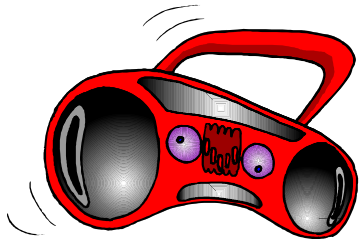
Sound is a pressure wave

The acoustic pressure is the change of pressure around the static (ambient) pressure

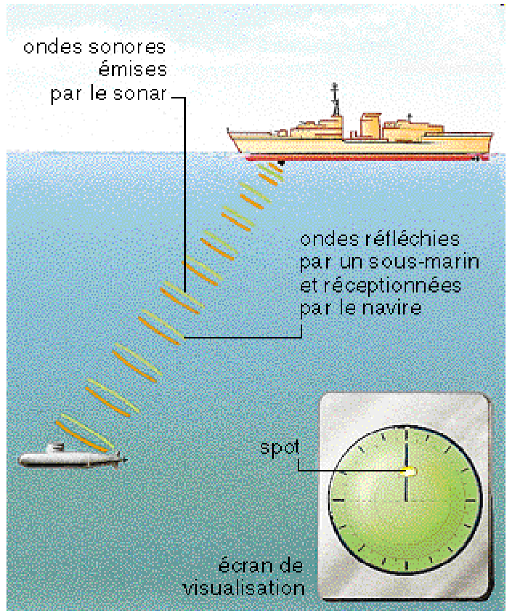


• Probe ⇔ Microphone + Loudspeaker

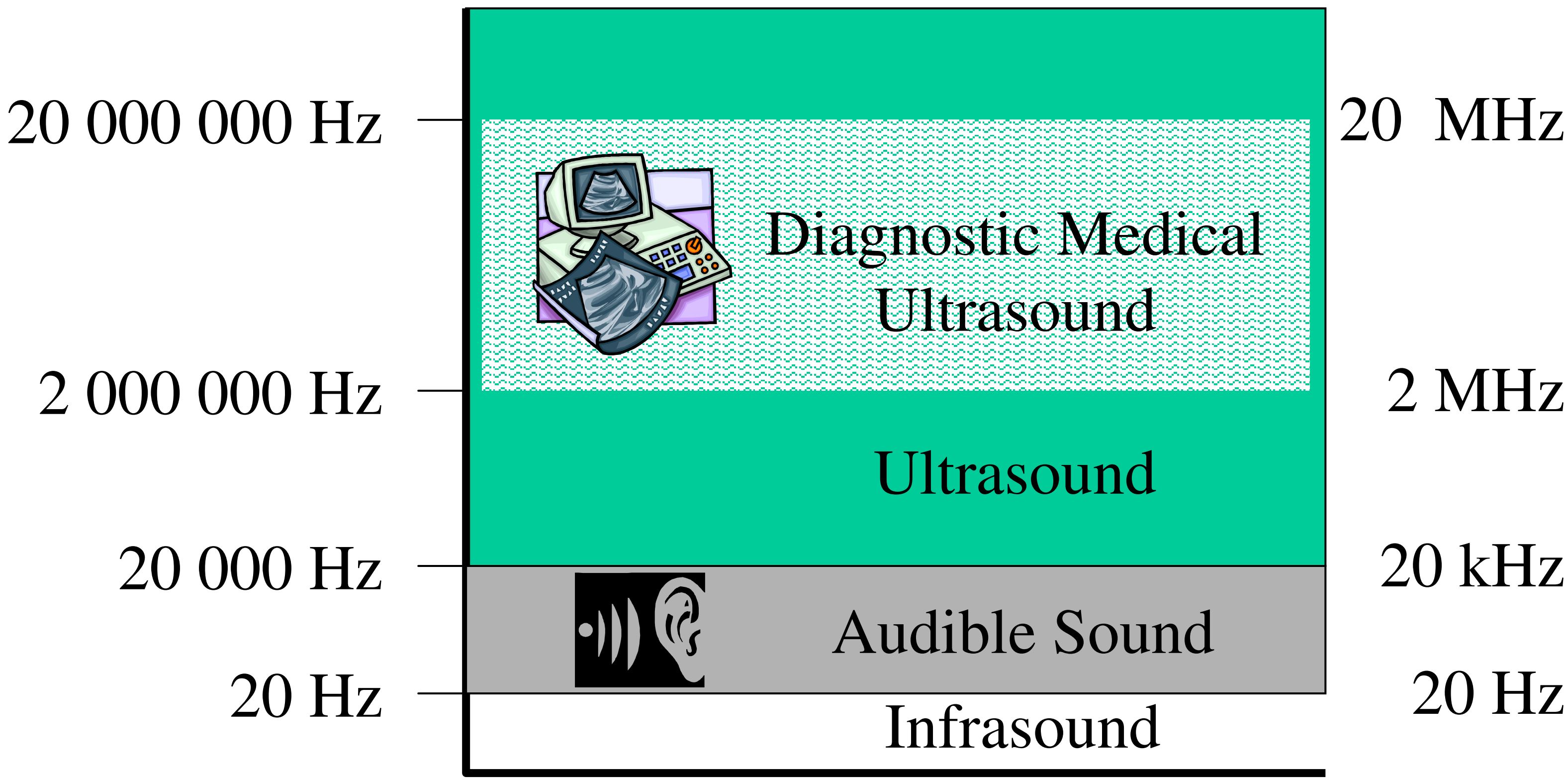


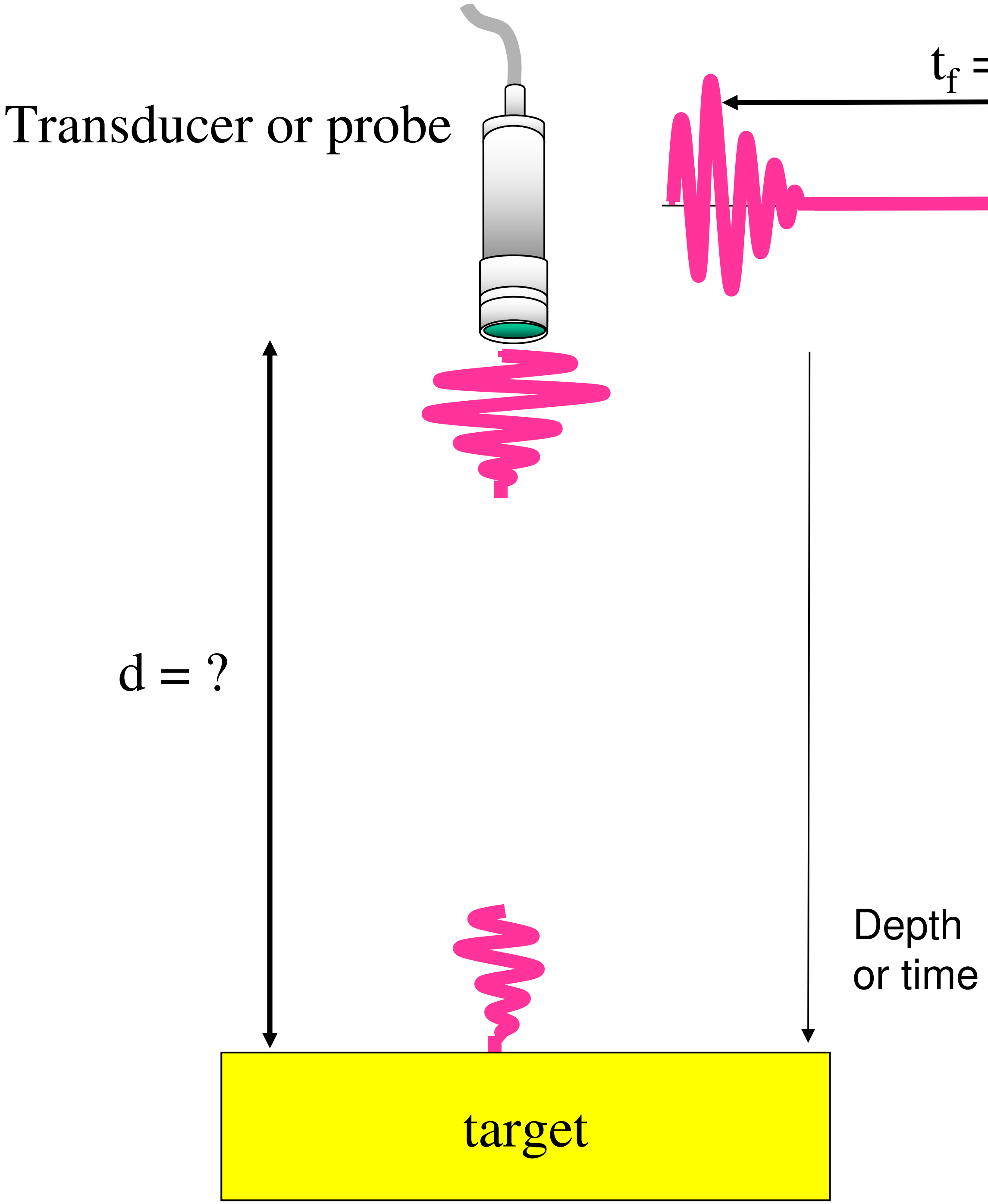


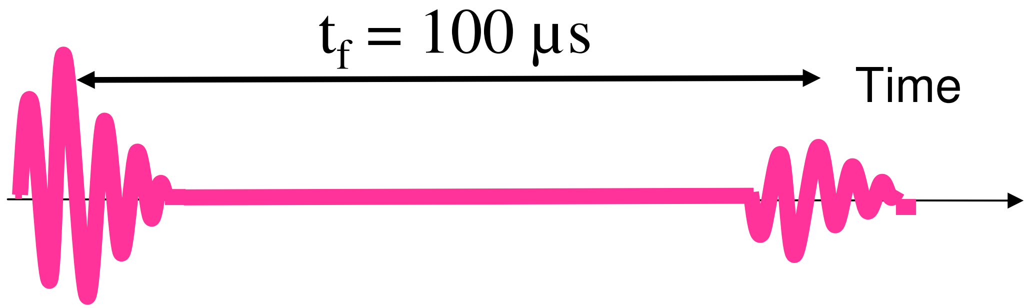
• Ultrasound scanner work as sonar



Frequency of Sound





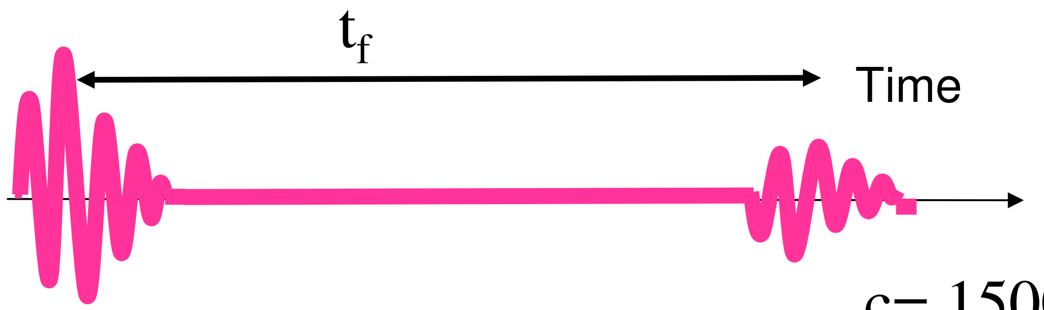


c= 1500 m/s

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

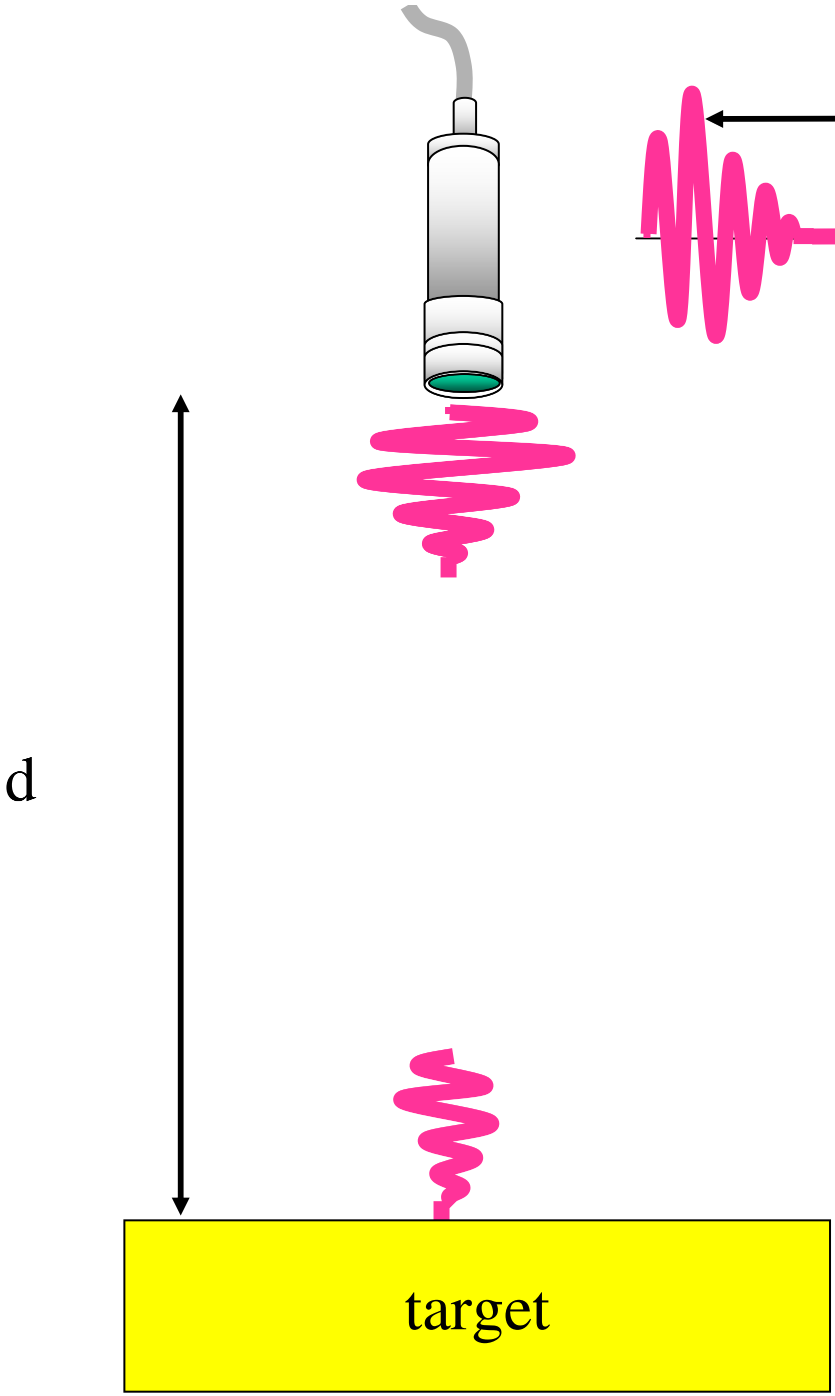
d = ?

d = 7. 5 cm



c= 1500 m/s

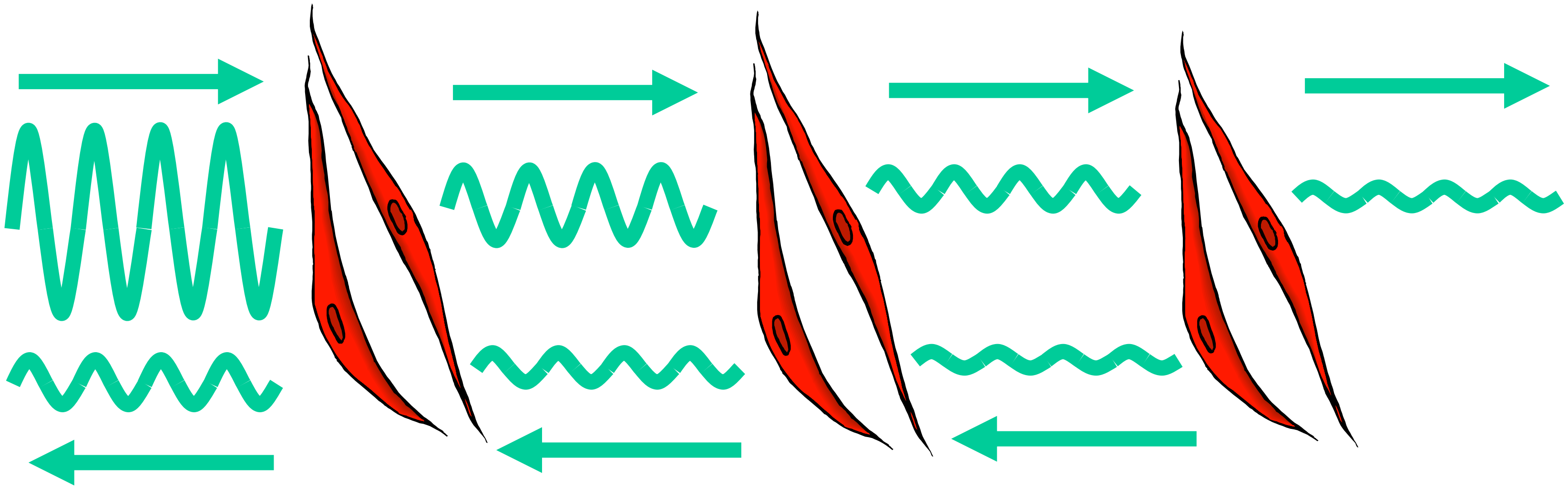
$$d = \frac{c \cdot t}{2}$$



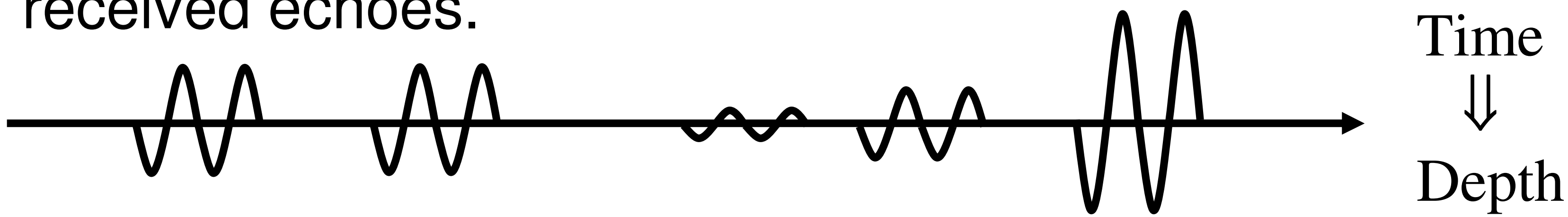
0.75 cm < depth < 15 cm

10 μs < t_f: time of flight < 200 μs

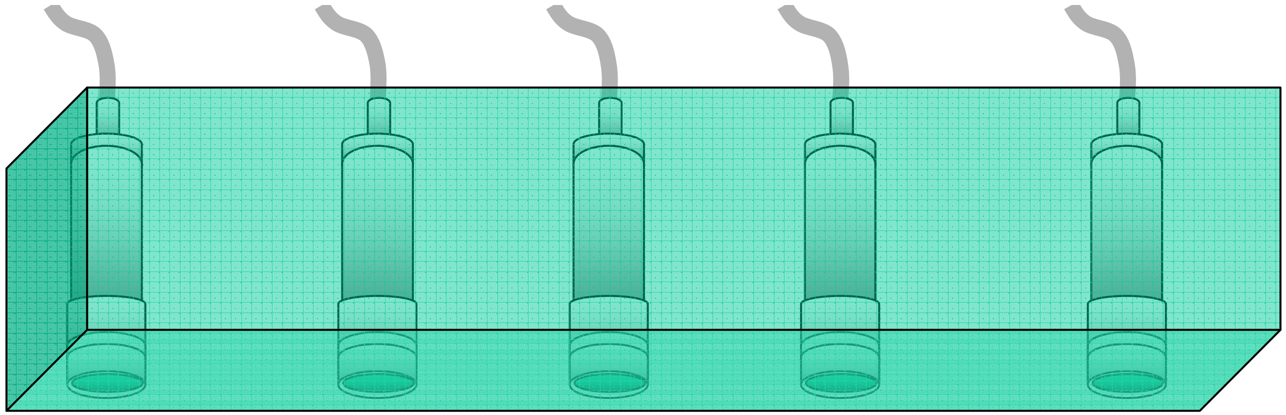
Reflection and transmission



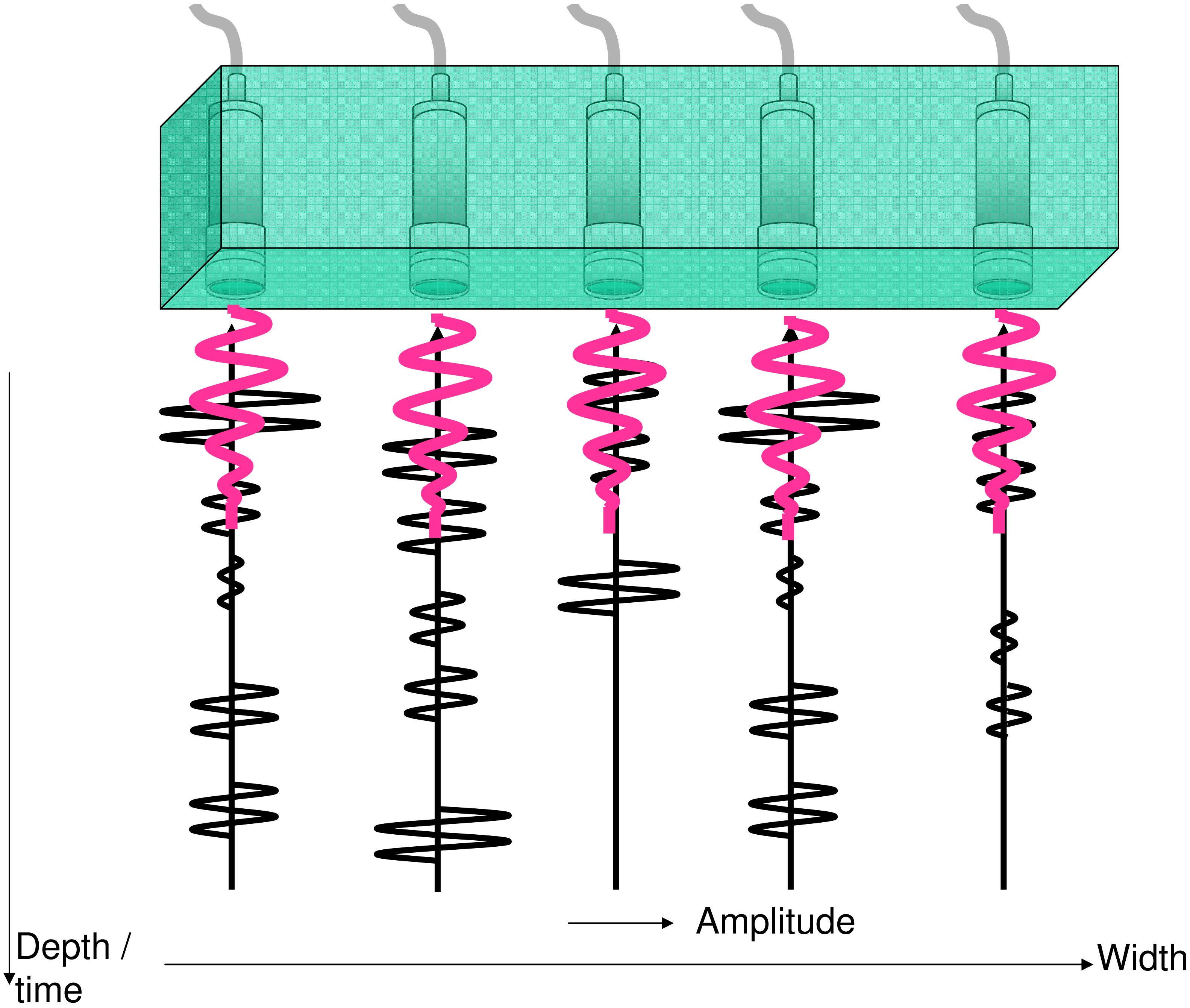
One transmitted pulse gives rise to a **train** of received echoes.

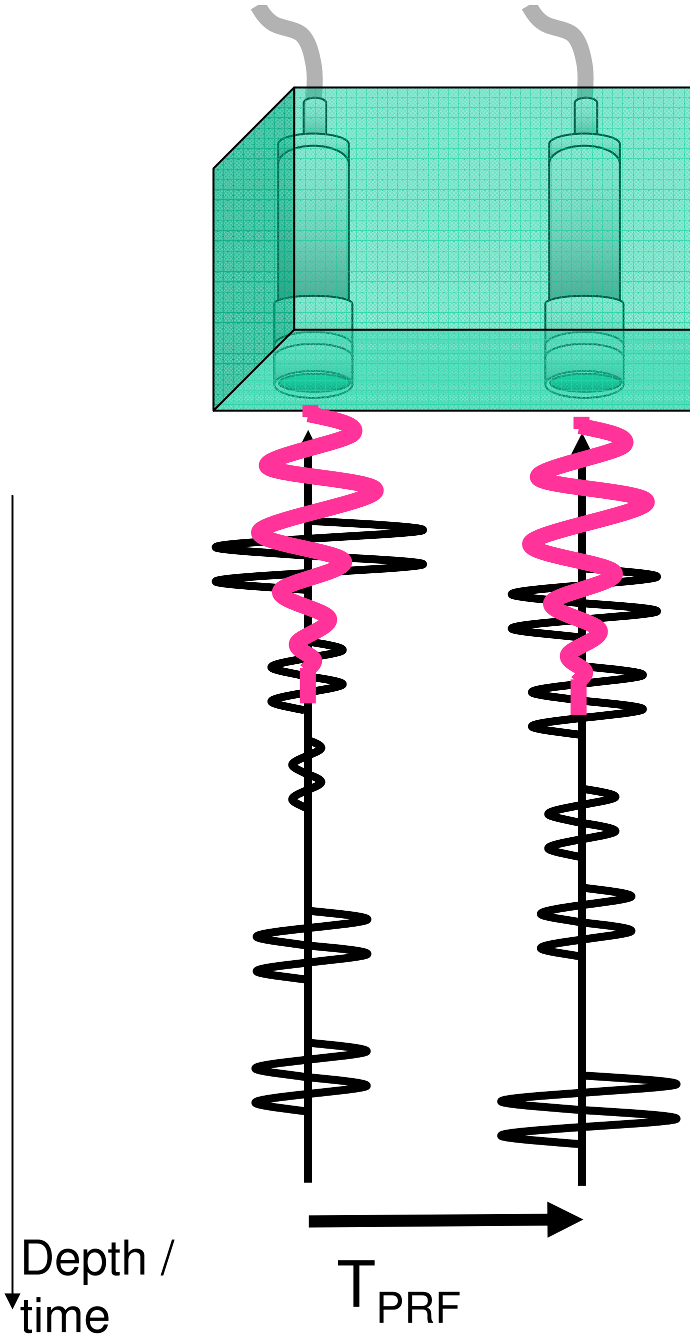


We can calculate **where** the echoes have come from by **timing** how long they take to get back.



64 to 512
Transducer elements


Amplitude
Depth /
time
Width



0.75 cm < depth < 15 cm

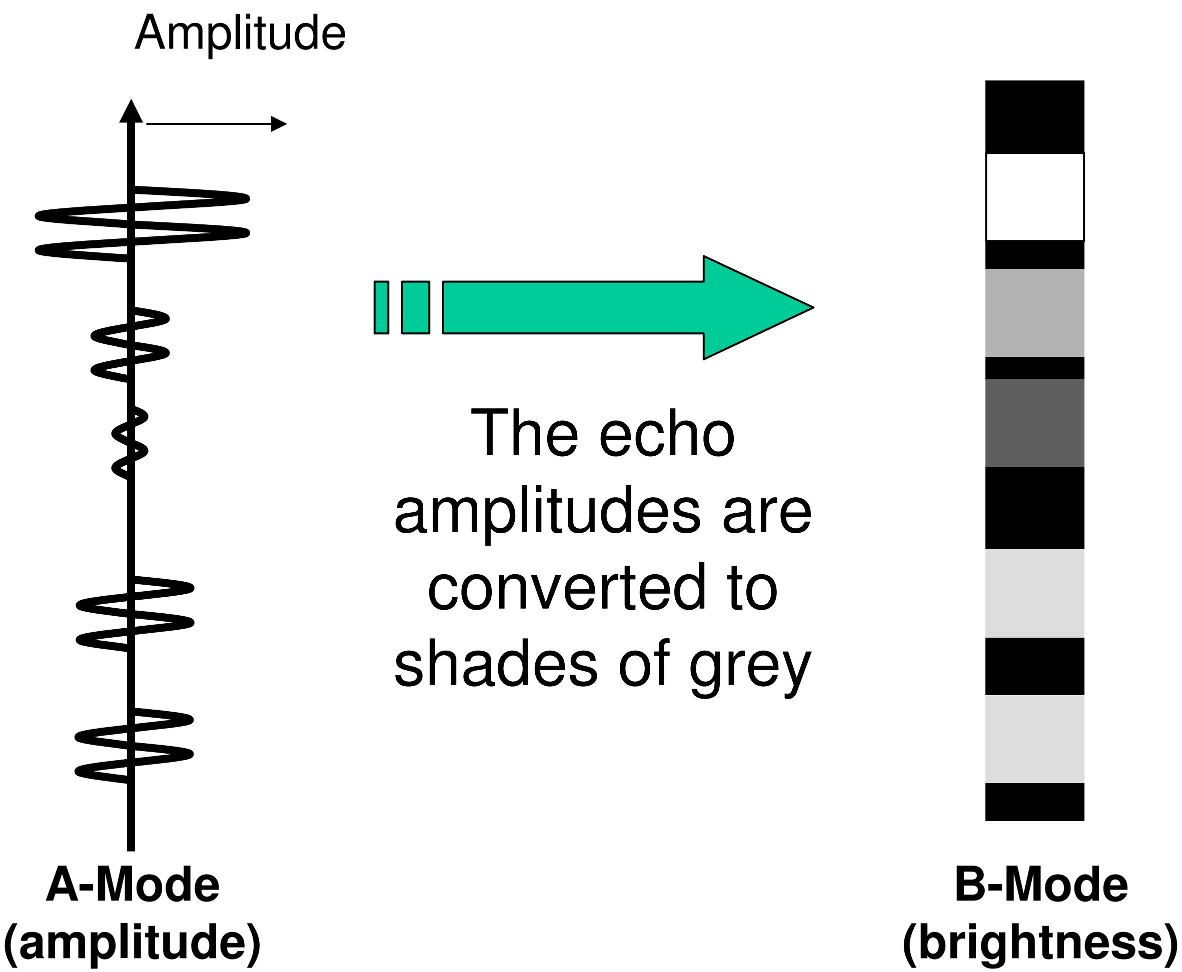
10 µs < time of flight < 200 µs

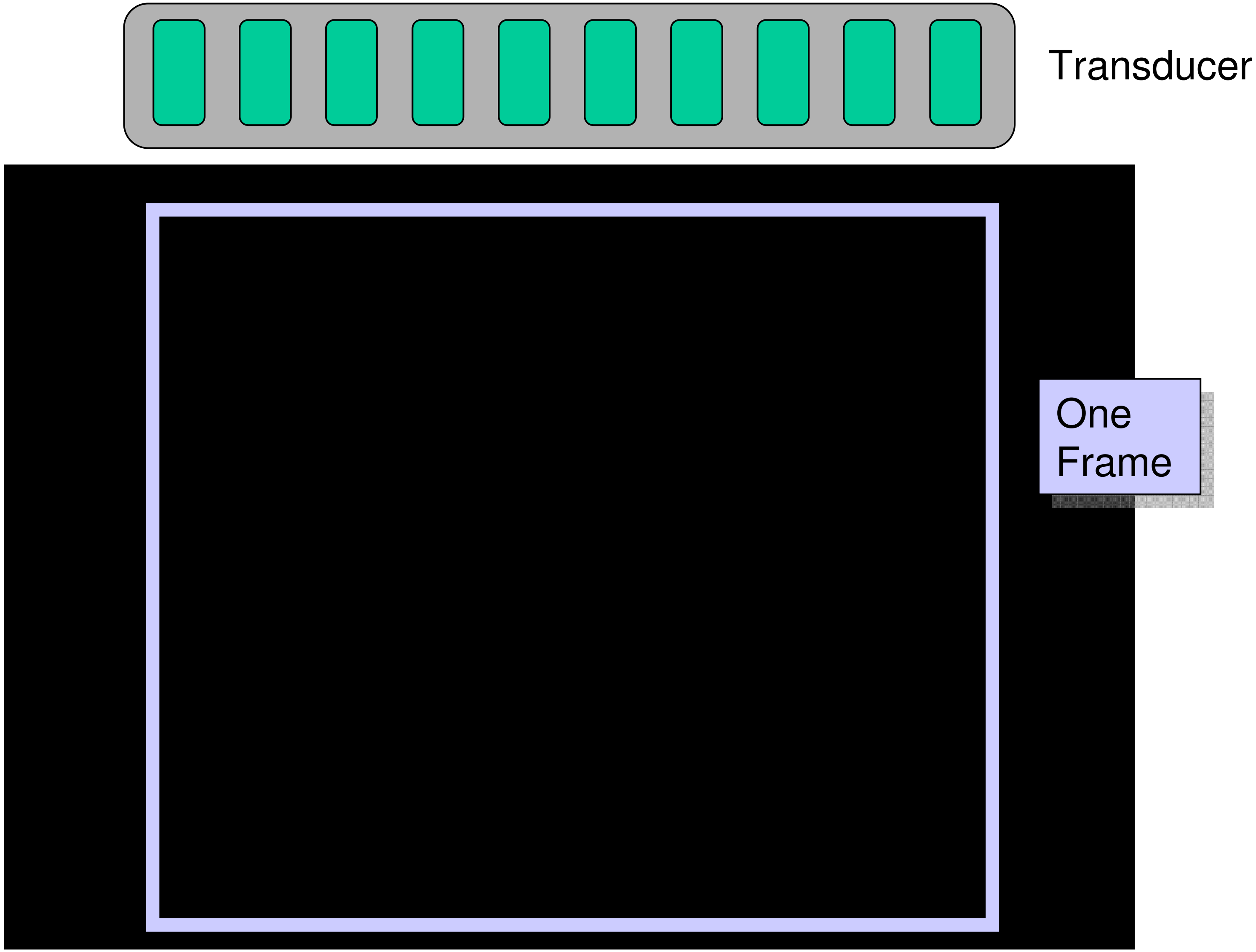
T_{PRF} >> maximum time of flight

$PRF = 1/ T_{PRF}$

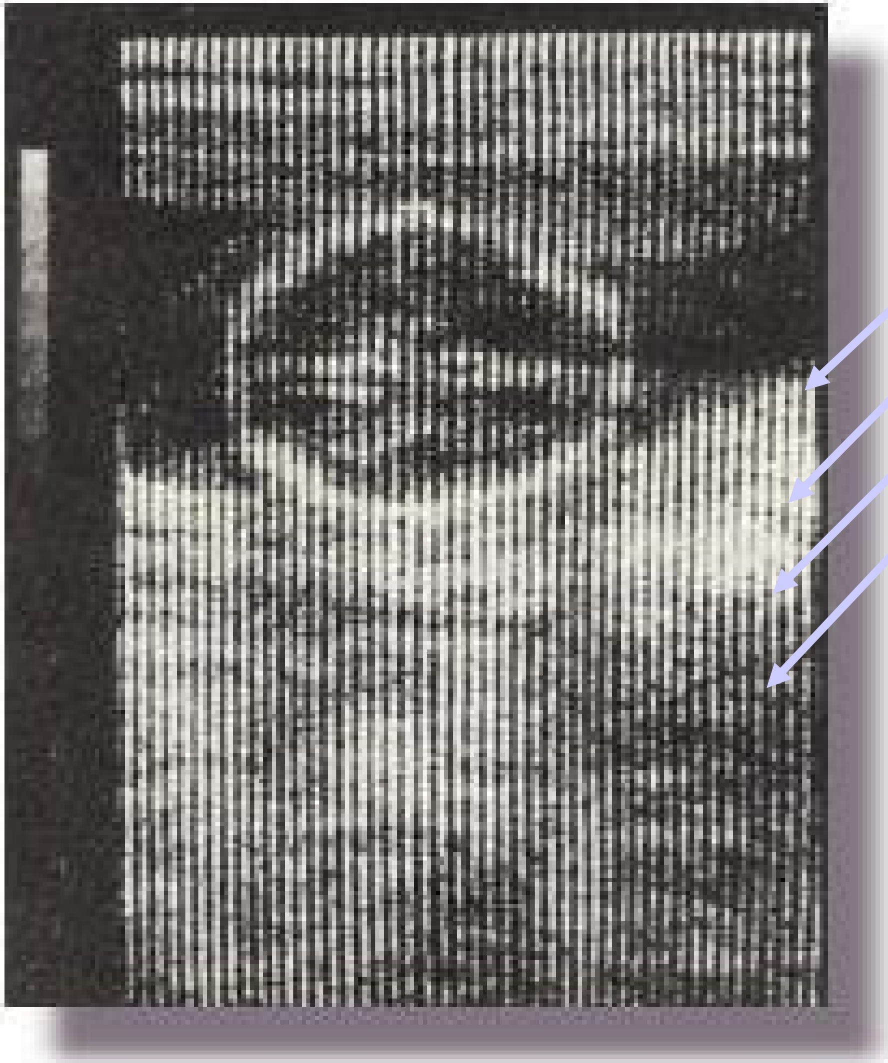
PRF: Pulse Repetition Frequency

Echoes from ONE pulse

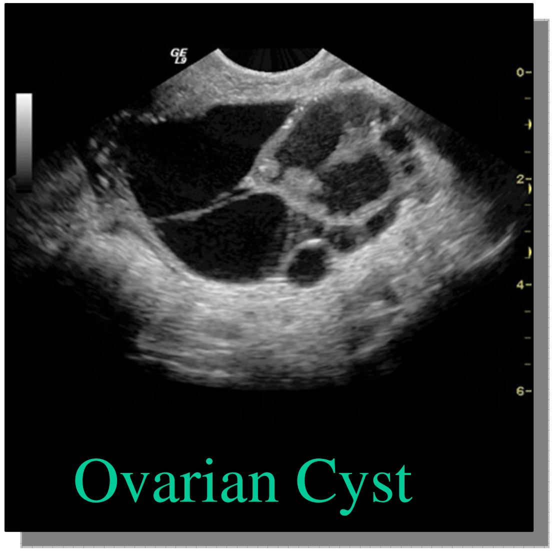



Transducer
One
Frame

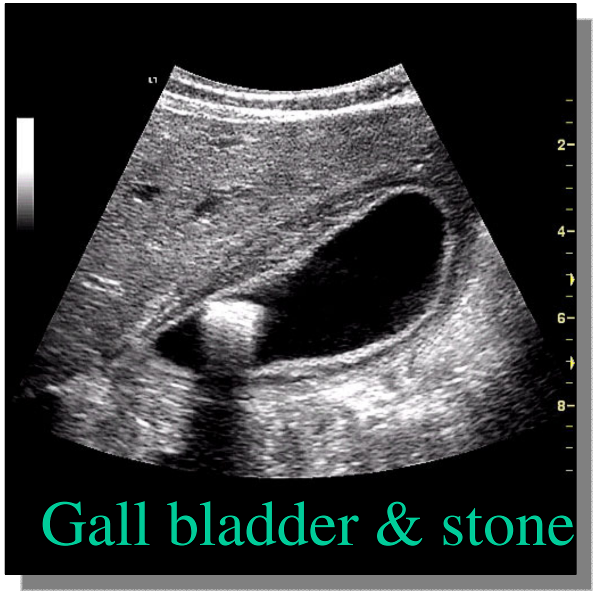
1970’



Visible scan lines (48)

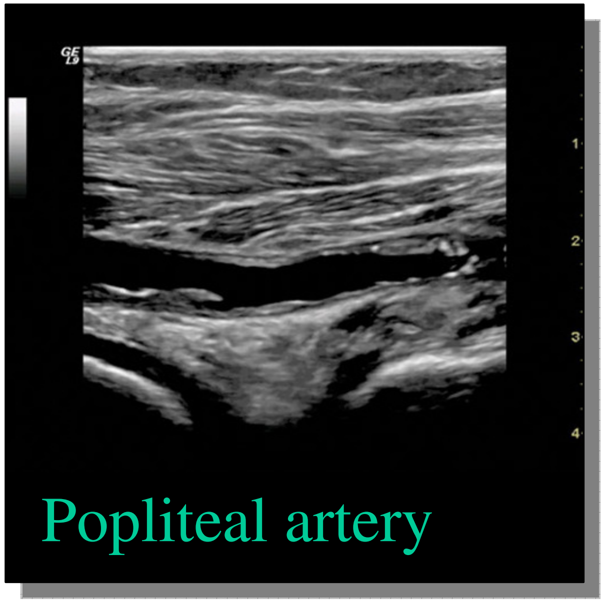


Ovarian Cyst

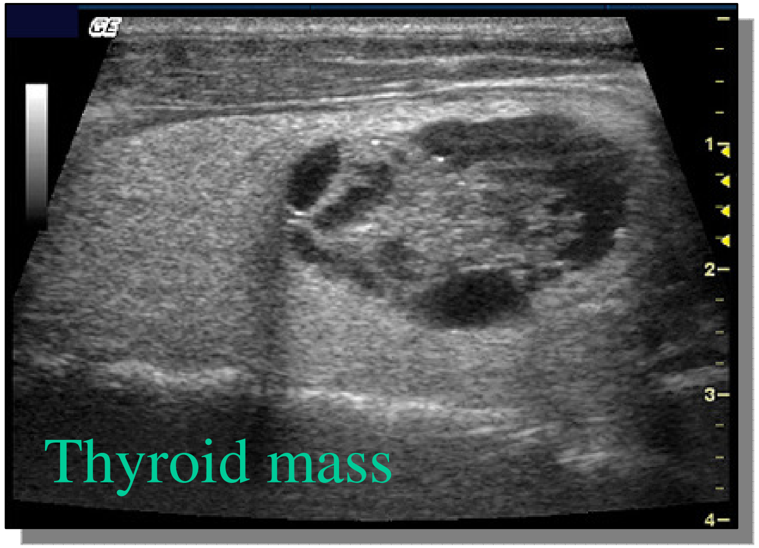


Gall bladder & stone

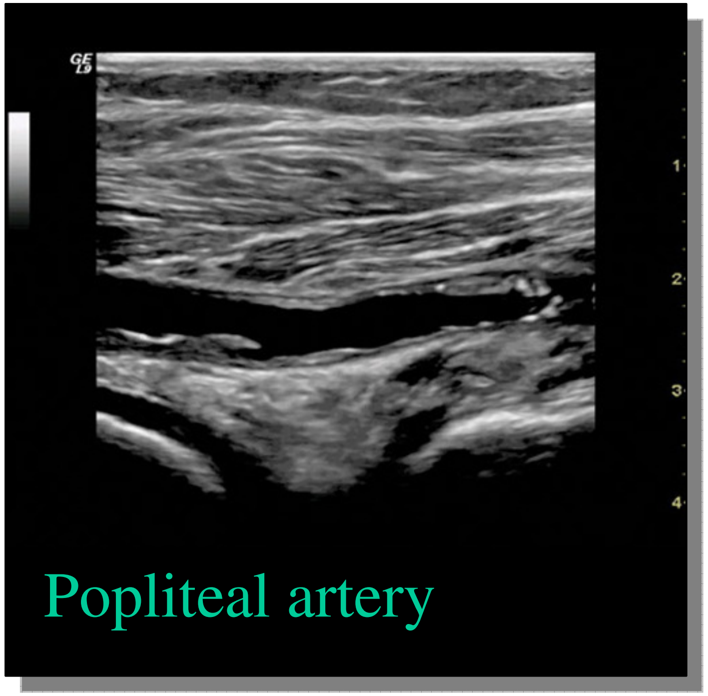
B (Brightness) Mode Images

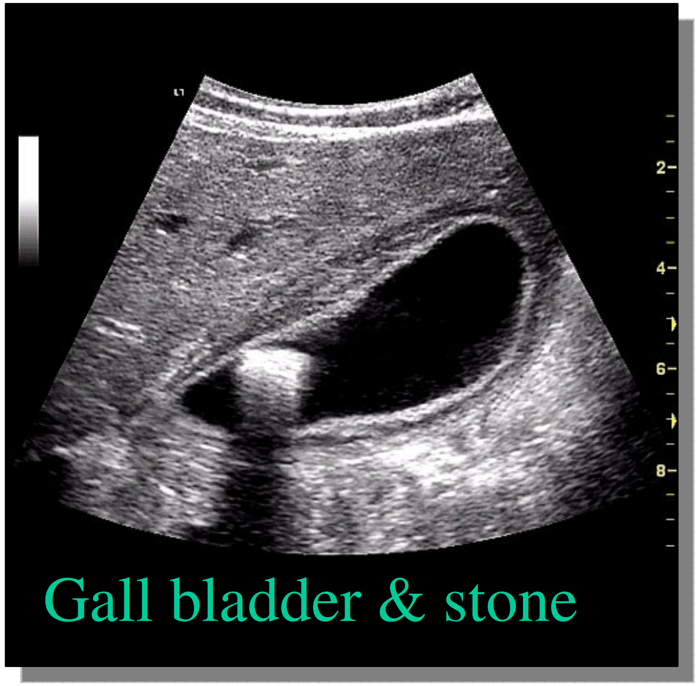


Popliteal artery



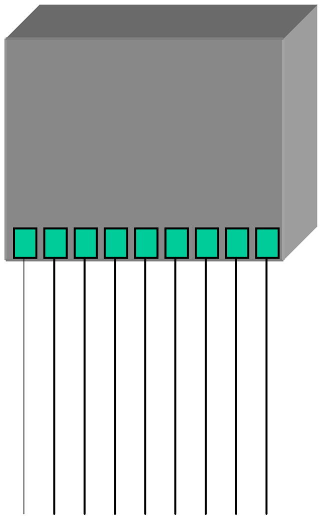
Thyroid mass

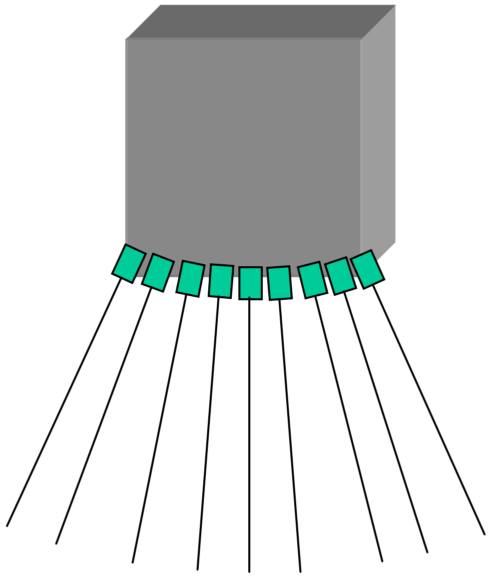




Linear probe

Sectorial probe



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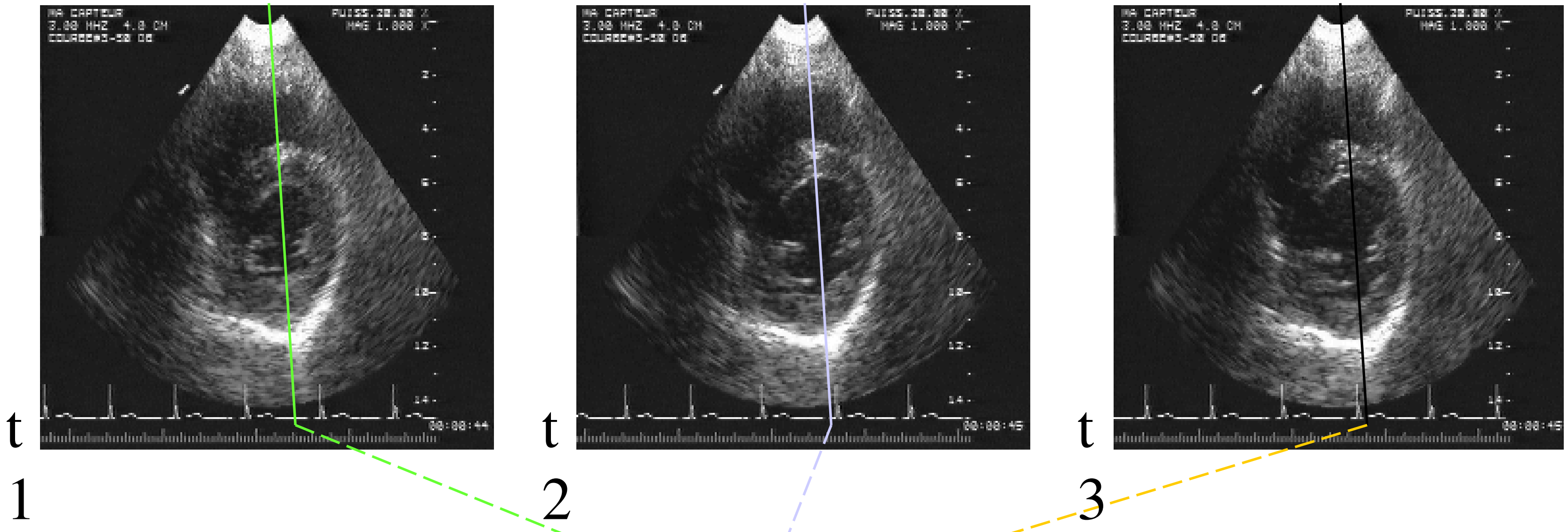
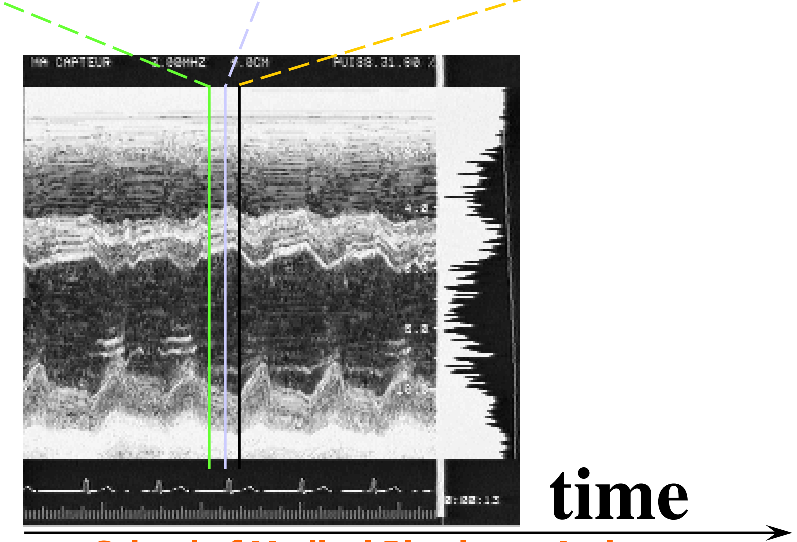
- # B-mode



- # M-mode

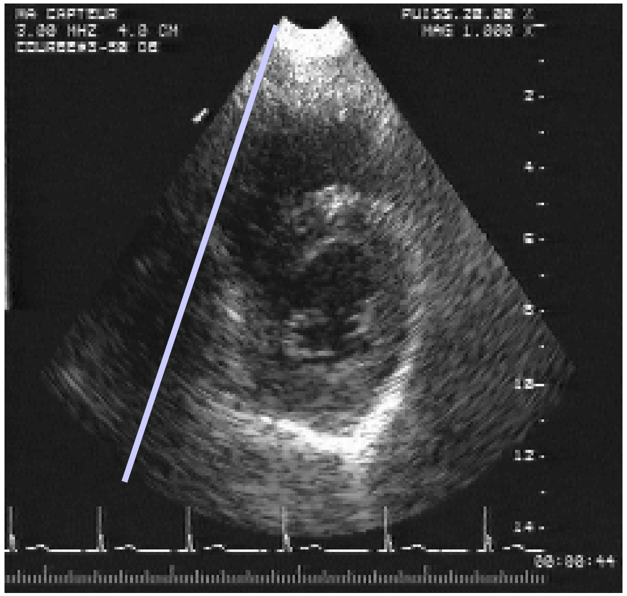
(or TM mode, Time Motion)



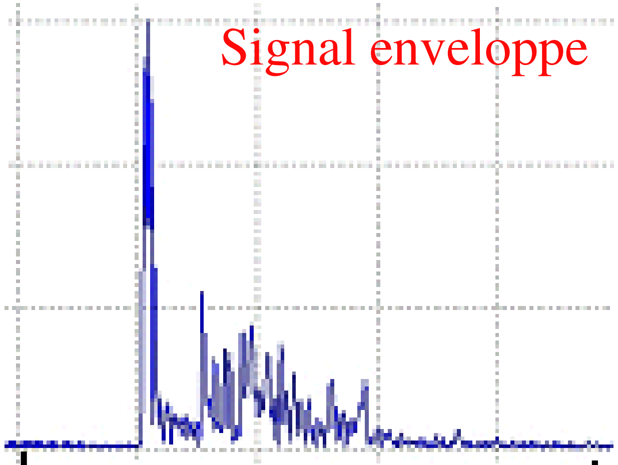
Imaging modes

Scan plane

Distance (cm)



mode B

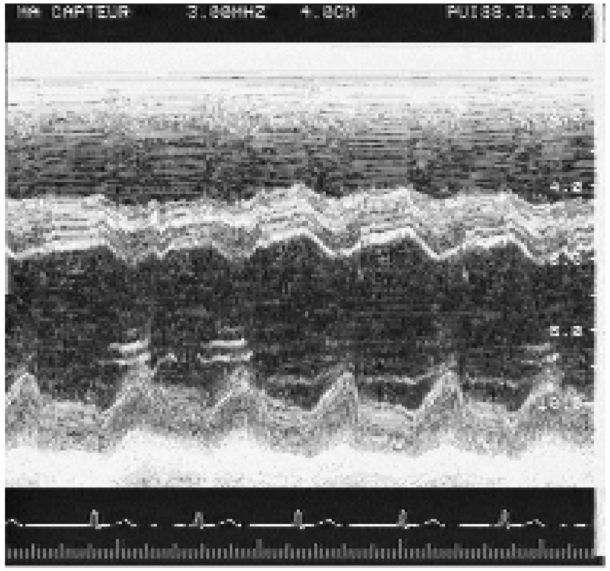


mode A

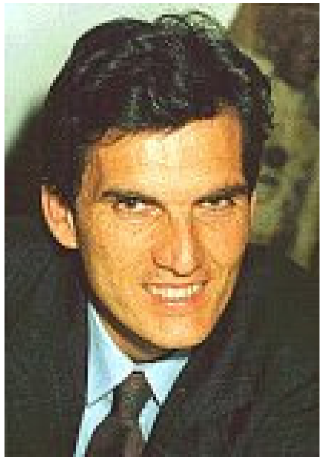
Depth (cm)

Time (s)

Depth (cm)

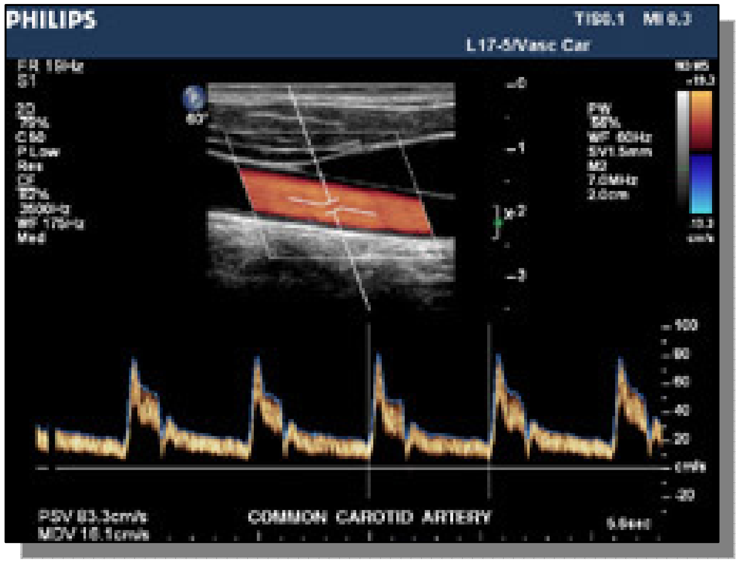


mode TM

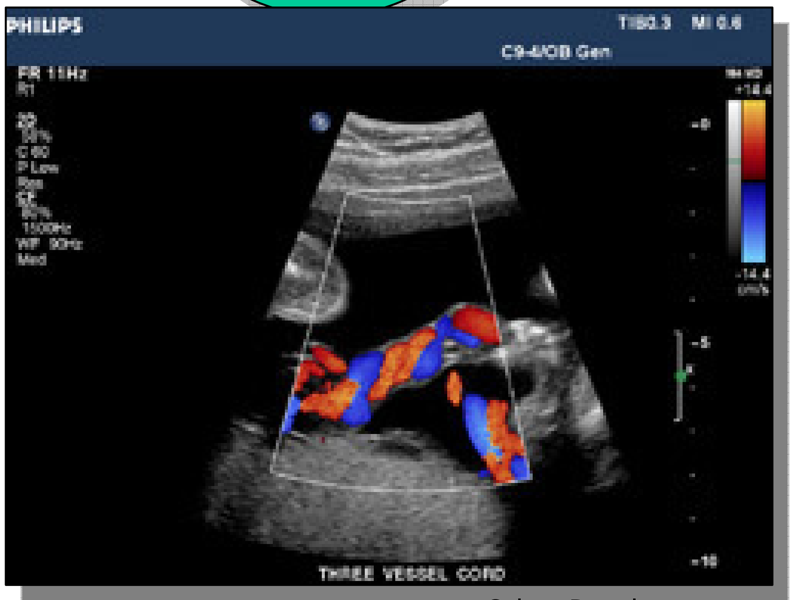


"Ultrasonic Doppler Modes"

Piero Tortoli

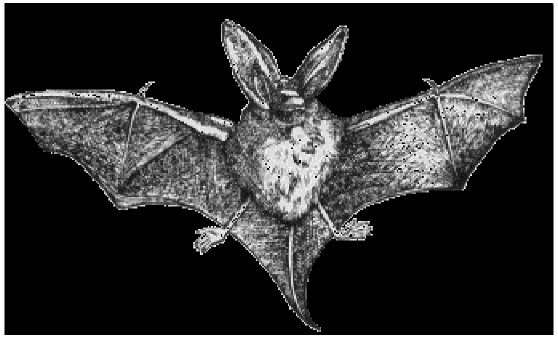


Spectral Doppler



Colour Doppler

History of Ultrasound



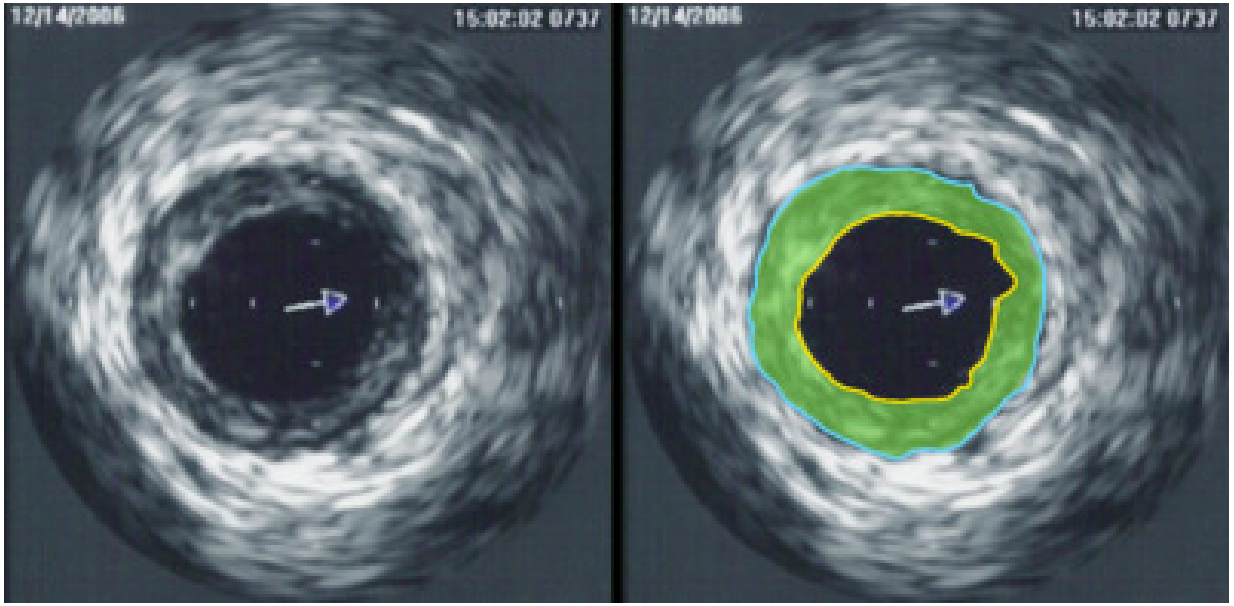
- **1794** Lazzaro Spallanzani discovered high frequency 'ultra'sound by demonstrating ability of bats to navigate by echo reflection
- **1876** Francis Galton invented a whistle that generated sound above the limit of human hearing
- **1880** Pierre Currie discovered the piezo-electric effect in certain crystals.

It was then possible for the generation and reception of ultrasound

"Medical Ultrasound Development over 40 years"

Nico de Jong

Intravascular Imaging



"Intravascular Imaging"
Nico de Jong

Basic Principles of Ultrasound

1: Overview & History

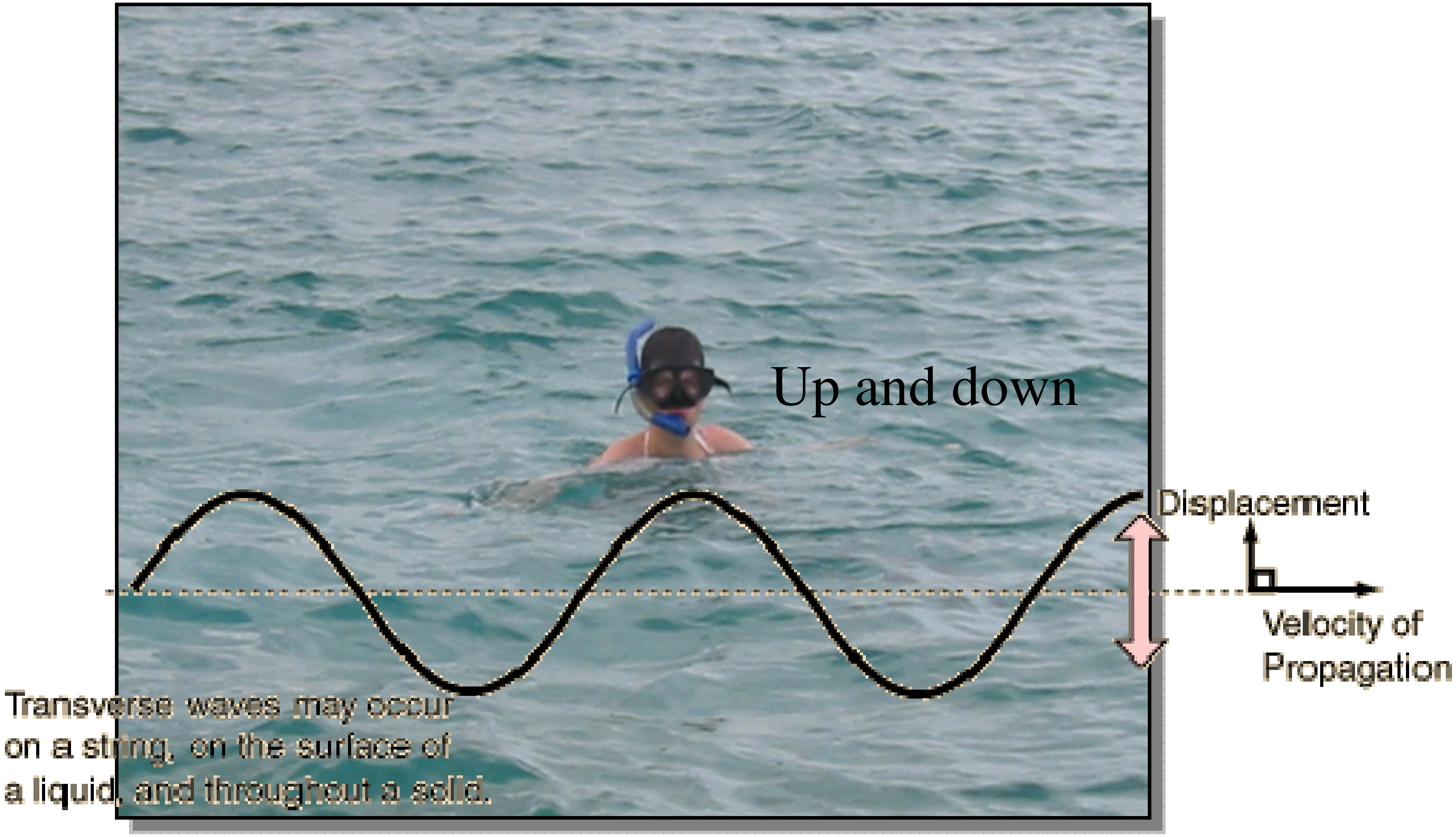
2: Sound Waves

3: Ultrasound generation

4: Ultrasound in Tissue

Waves

Wave Motion

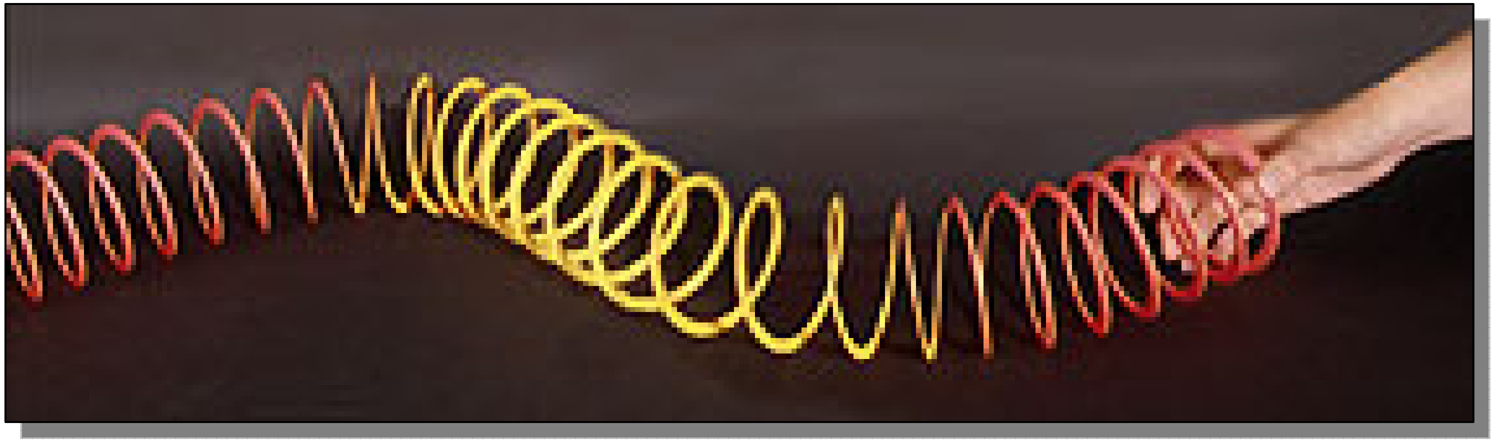

Up and down
Displacement
Velocity of Propagation
Transverse waves may occur on a string, on the surface of a liquid, and throughout a solid.

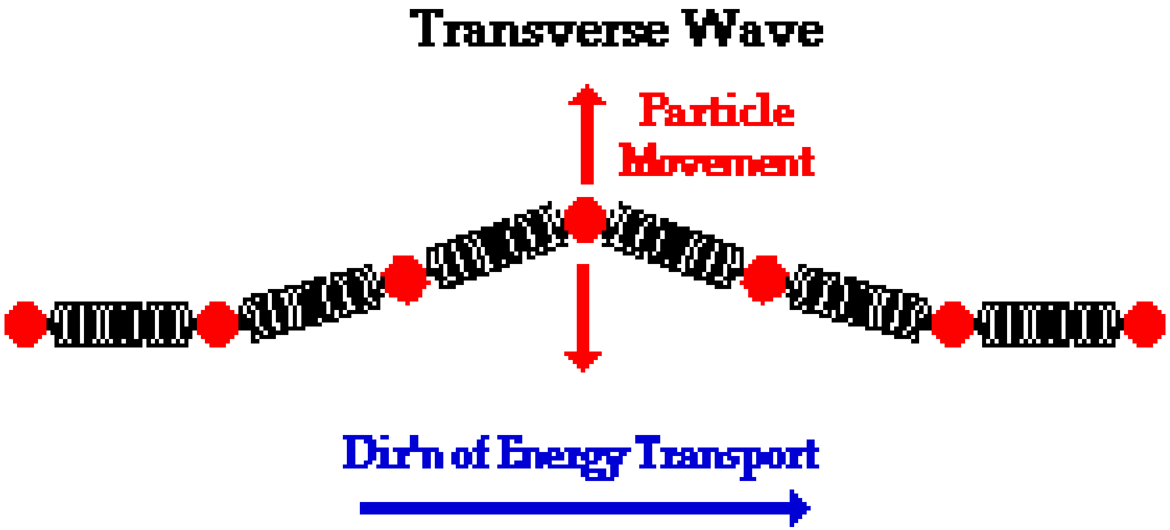
Wave Motion

Transverse wave

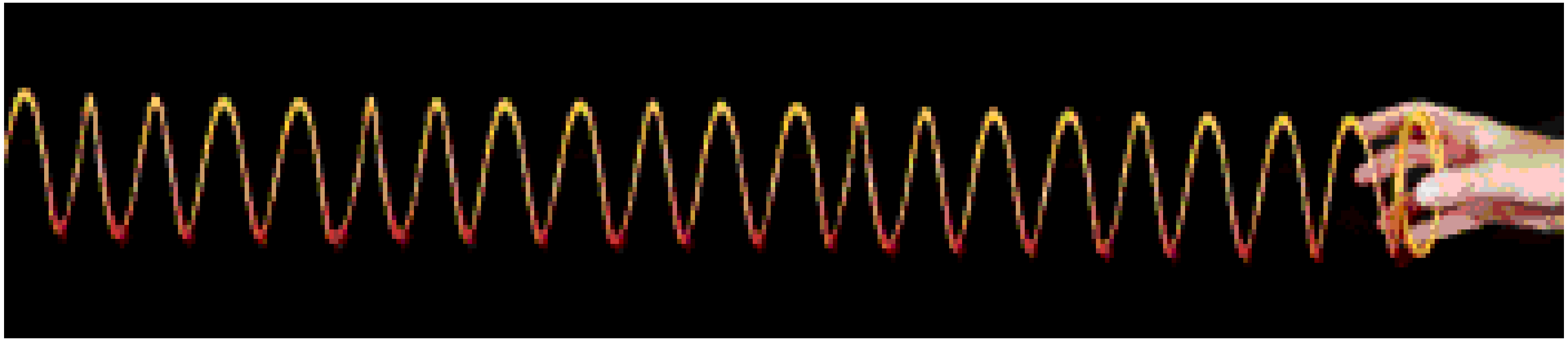
Stadium wave

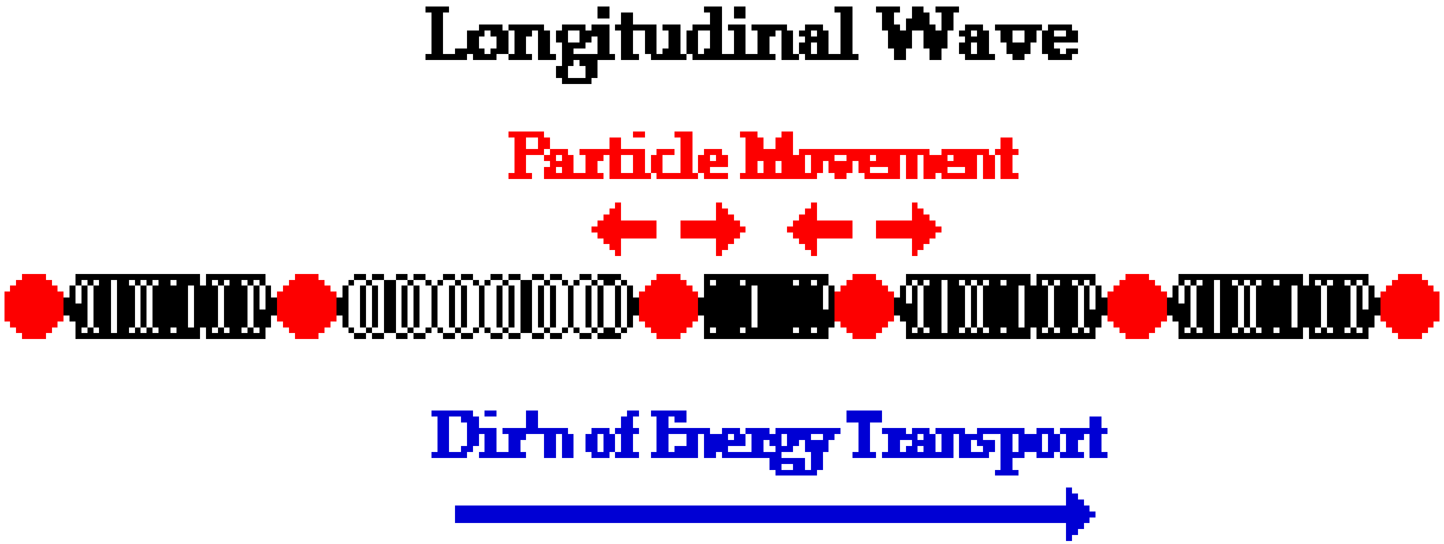
Transverse Wave





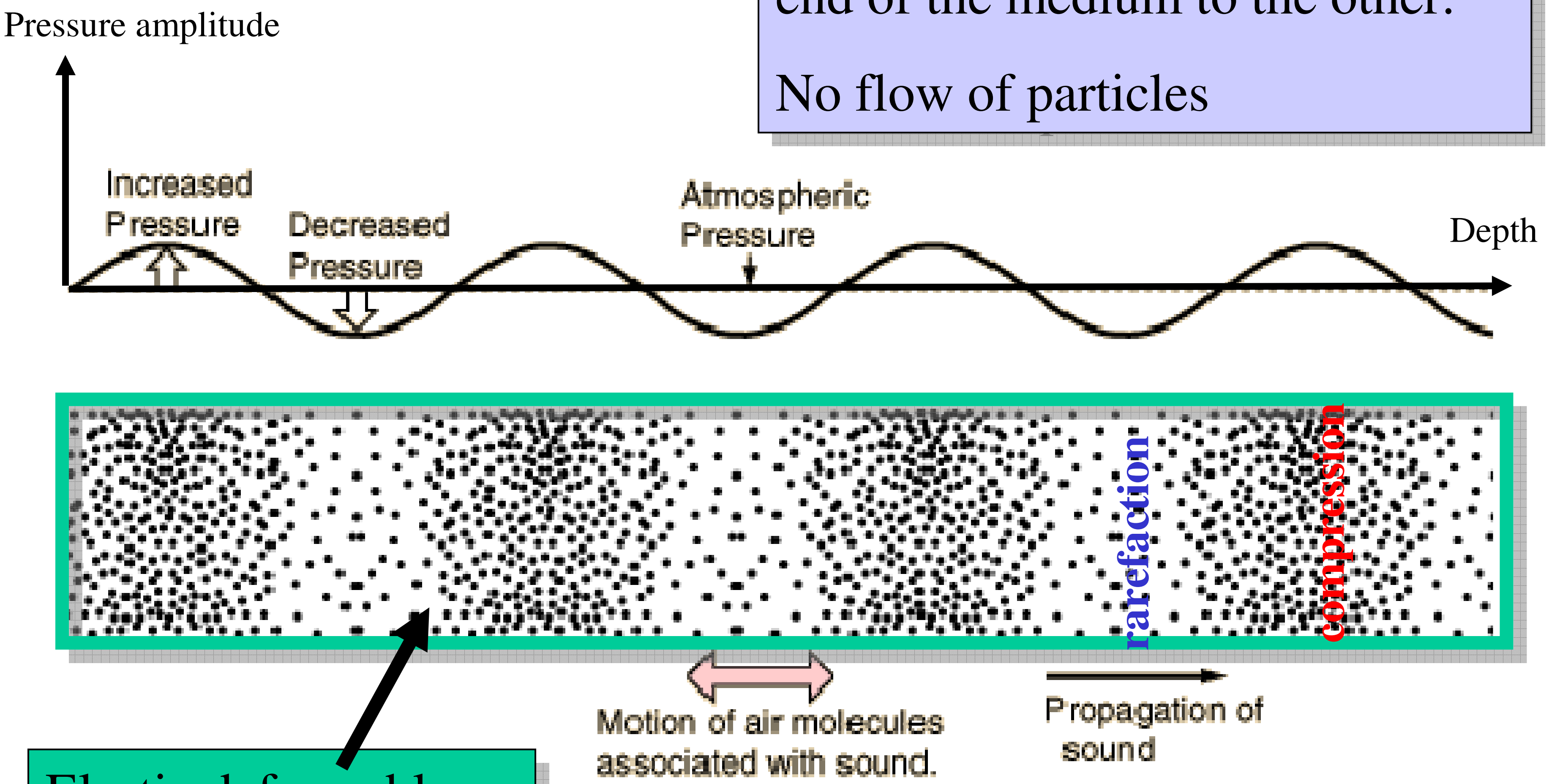
Longitudinal Wave





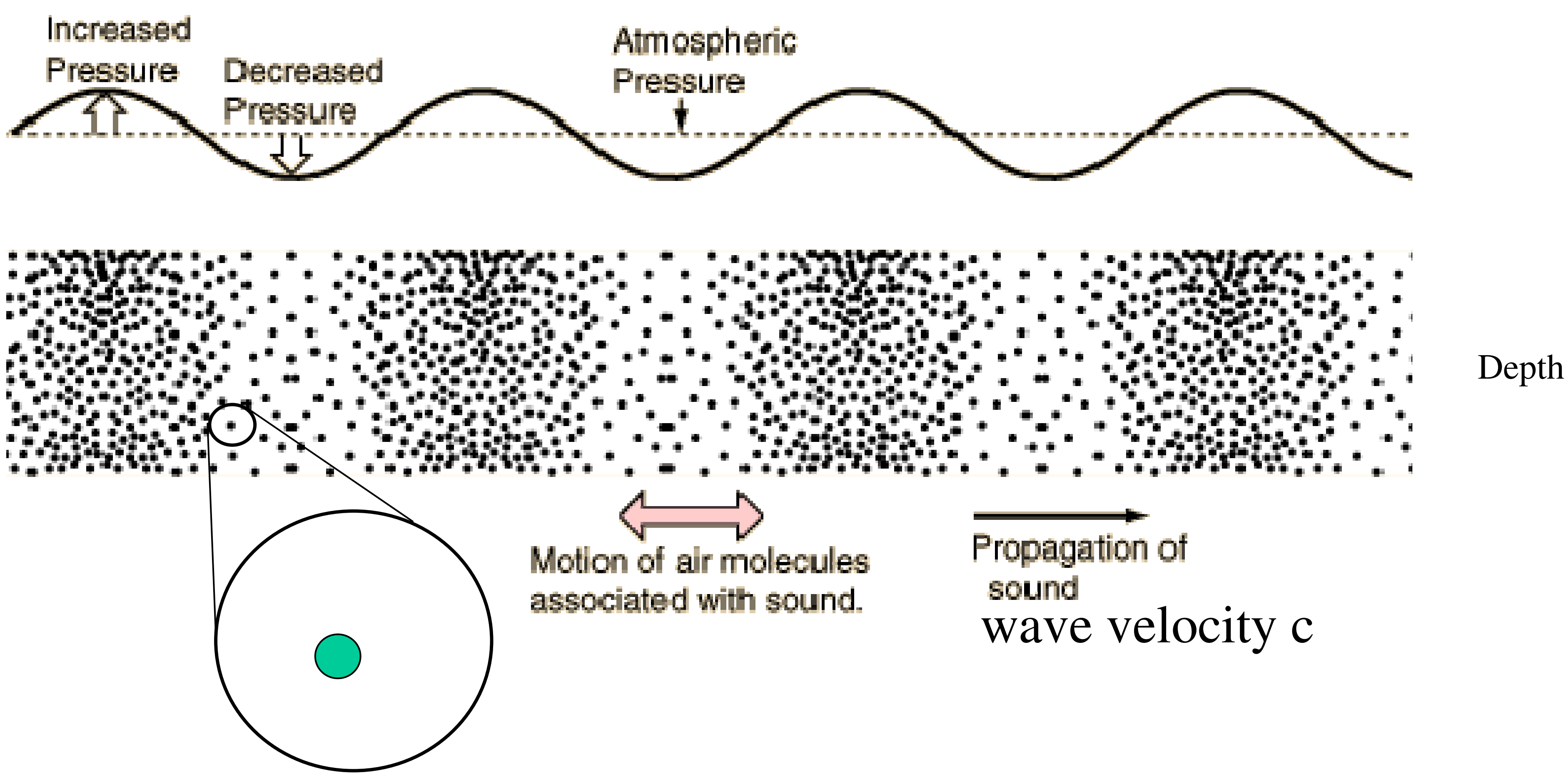
Molecules do not travel from one end of the medium to the other.

No flow of particles



Elastic deformable medium – gas, liquid or solid.

wave velocity c



At each spatial position , the material points are oscillating around their equilibrium position (particle velocity v)

Molecules do not travel from one end of the medium to the other.

The Nature of a Sound Wave

- Sound is a mechanical wave
  - Created by a vibrating object
  - Propagated through a medium
- Sound is a longitudinal wave
  - Motion of particles is in a direction parallel to direction of energy transport
- Sound is a pressure wave
  - Consists of repeating pattern of high and low pressure regions

The Frequency of a wave

T = 1 / f

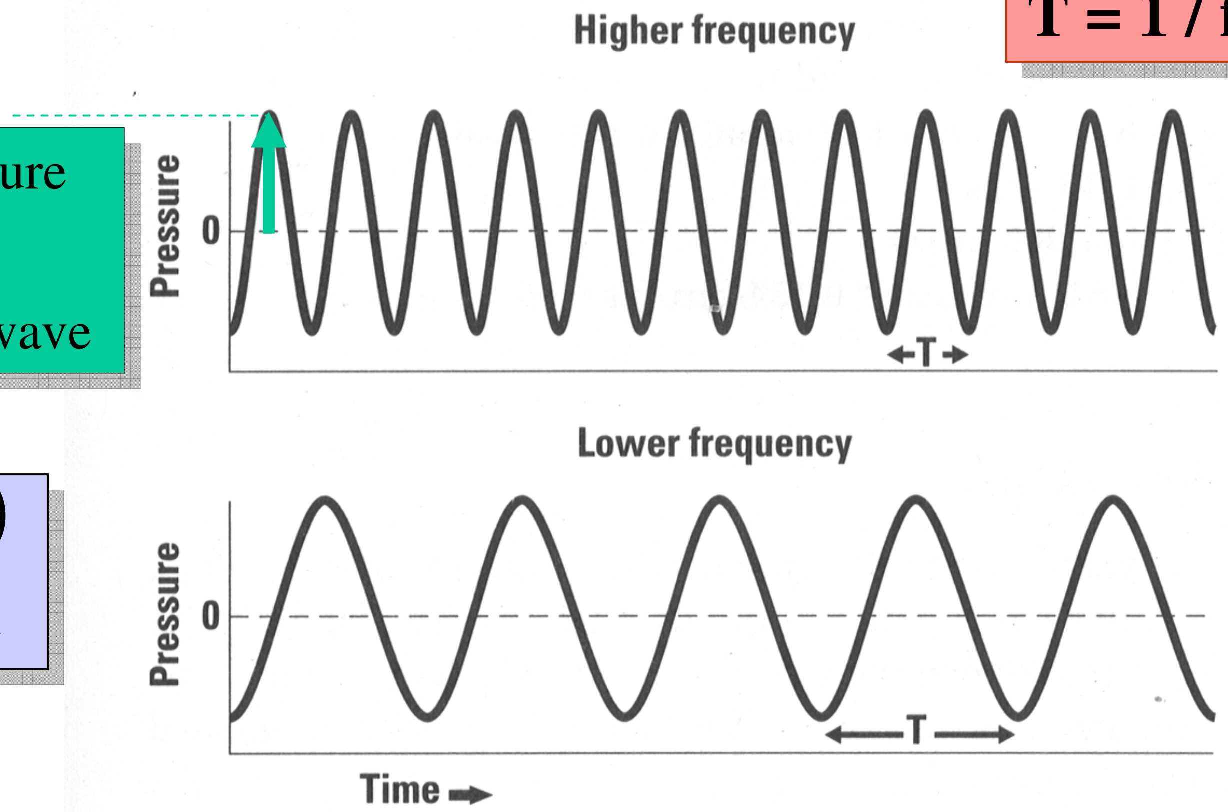
Peak excess pressure

=

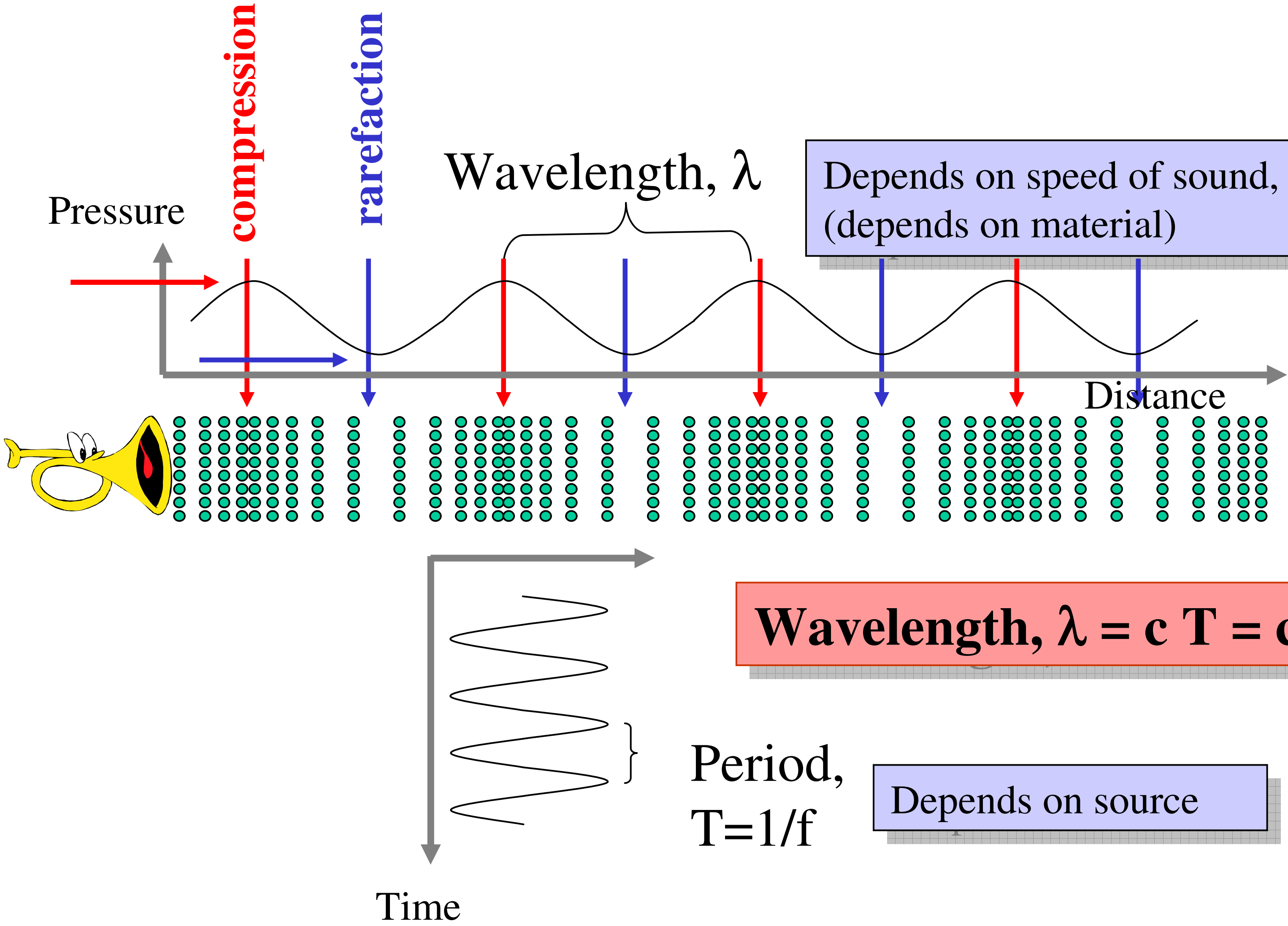
amplitude (A) of wave

$$A = A_0 \sin(2\pi f t)$$

Wave equation



Wavelength and Frequency



Depends on speed of sound, c (depends on material)

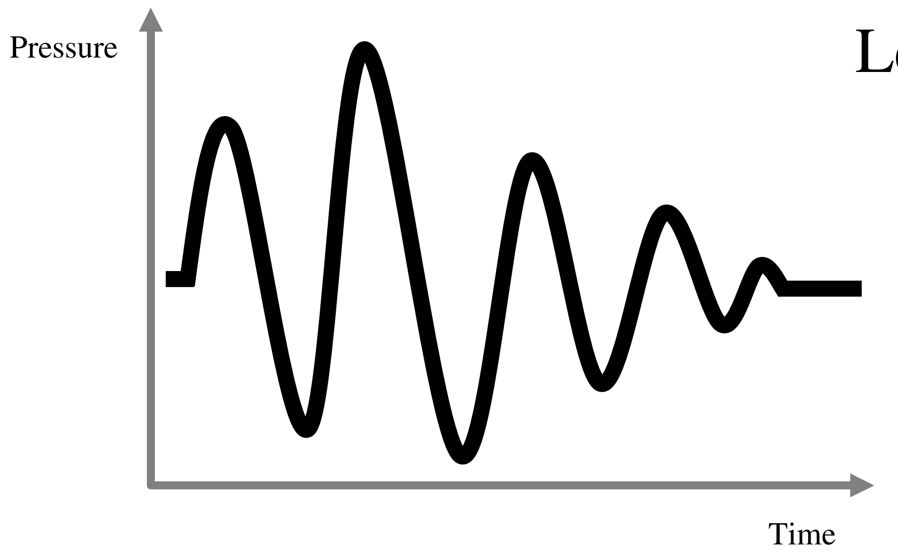
Wavelength, $\lambda = c\ T = c\ /\ f$

Depends on source


Air c=330m/s
Water c=1480m/s
If source= 3 MHz
$\lambda = 1480 / 3\,.10^6 = 493\ \mu m$

Ultrasound Pulse

- The majority of ultrasound is emitted as pulses



Length of pulse is about 3 to 5 period

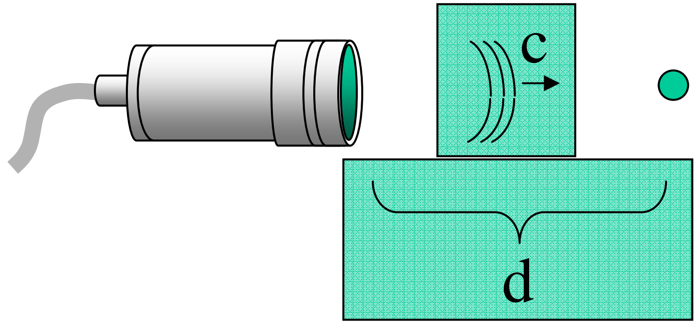
F = 3 MHz

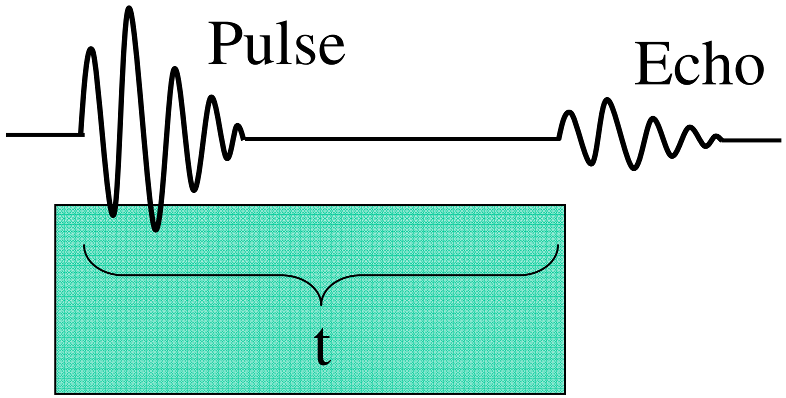
$1\ \mu s < T_p < 1.66\ \mu s$

Range Equation

- It is possible to predict the distance (d) of a reflecting surface from the transducer if the time (t) between transmission & reception of the pulse is measured and the velocity (c) of the ultrasound along the path is known

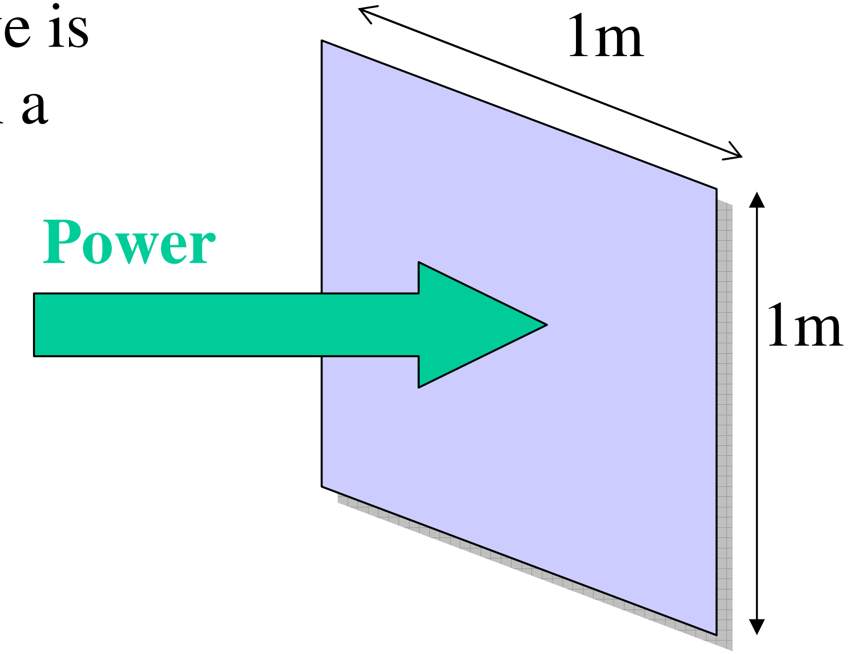
$$d = \frac{t \cdot c}{2}$$





Intensity

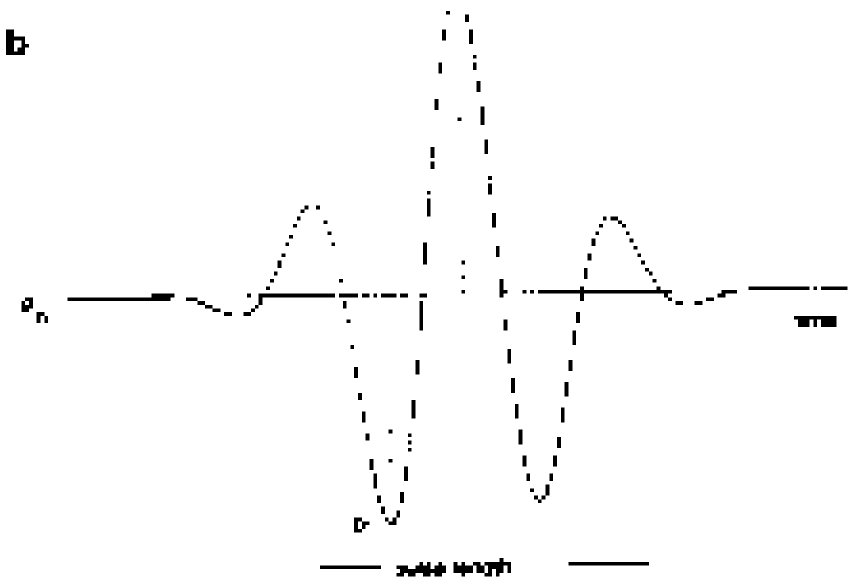
The intensity associated with the wave is defined as the power flowing through a unit area (measured in W/m² or mW/cm²)



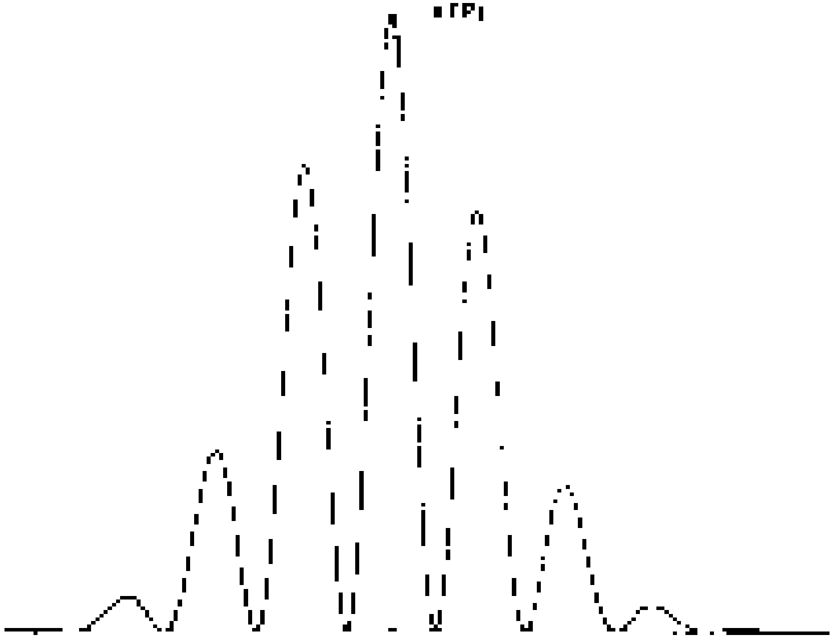
$$I_i\,(t,r) = \frac{p^2(t,r)}{\rho\ c}$$

- **Time averaged intensity** (I) for a **sinusoidal wave** (where P_o is the peak-pressure amplitude)

$$I = \frac{P_0^2}{2\rho c}$$

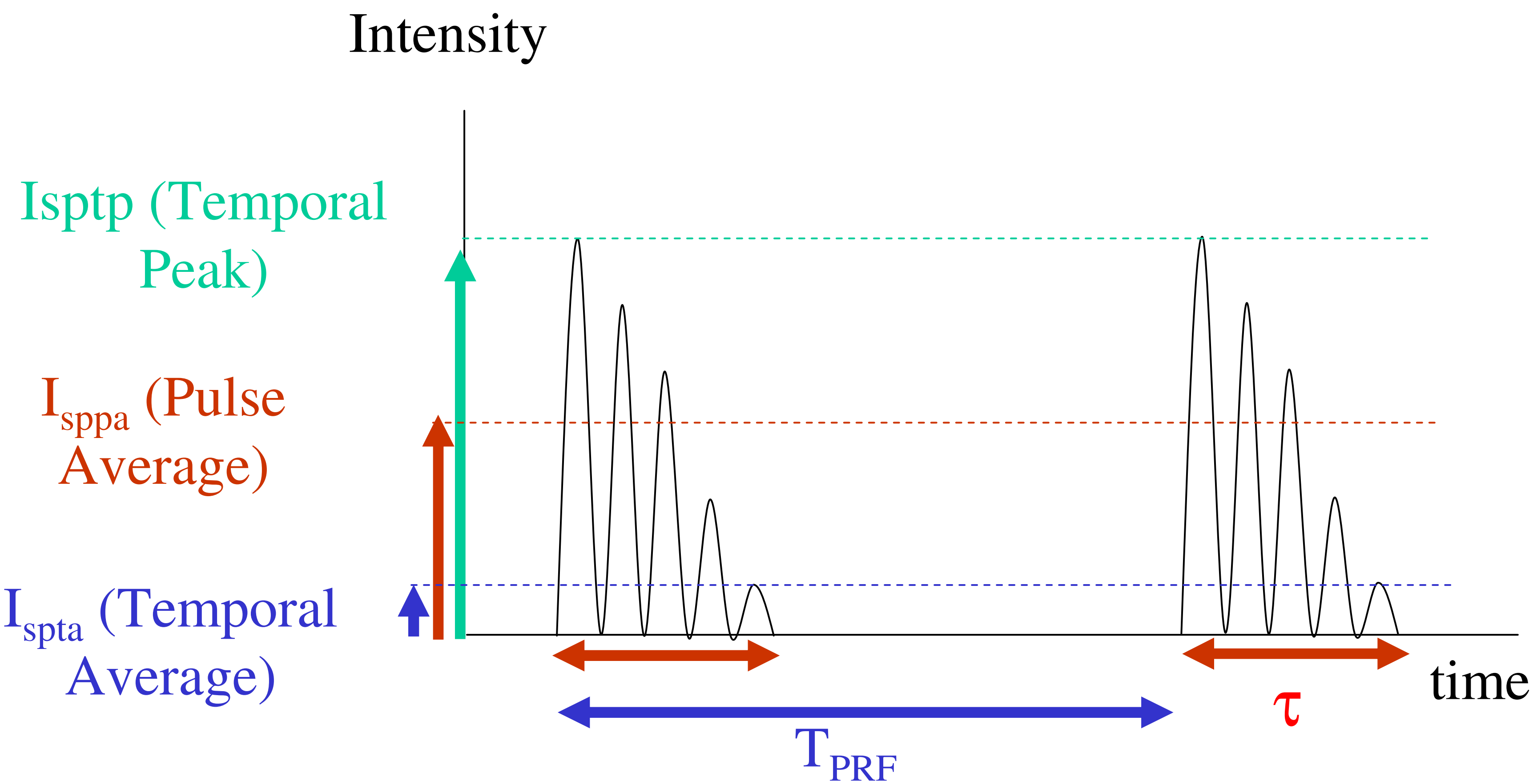


pression

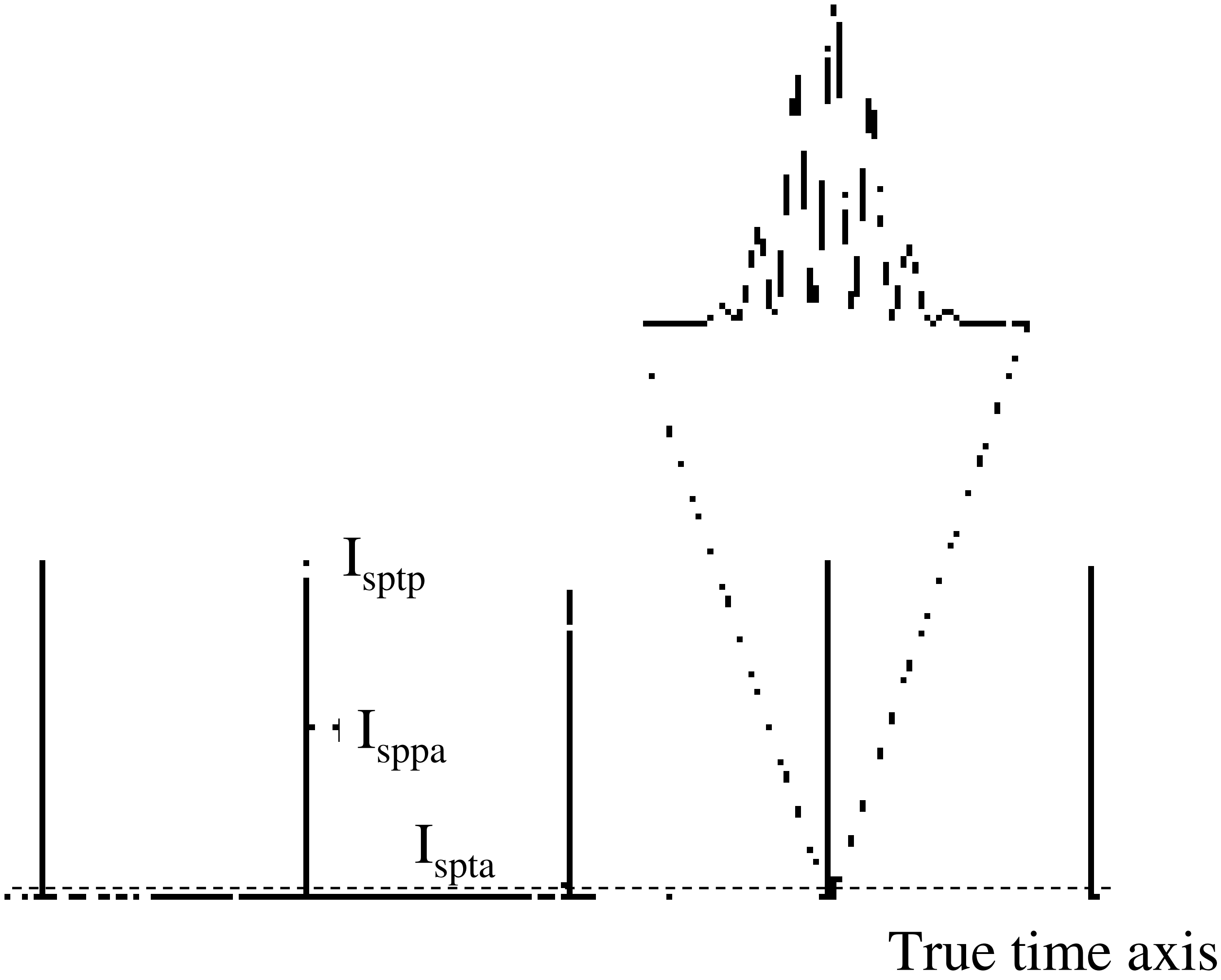


intensité

Intensity



$$\frac{\mathbf{I_{spta}}}{\mathbf{I_{sppa}}} = \frac{\boldsymbol{\tau}}{\mathbf{T_{PRF}}} \approx 1/200$$



Isptp
Isppa
Ispta
True time axis

Basic Principles of Ultrasound

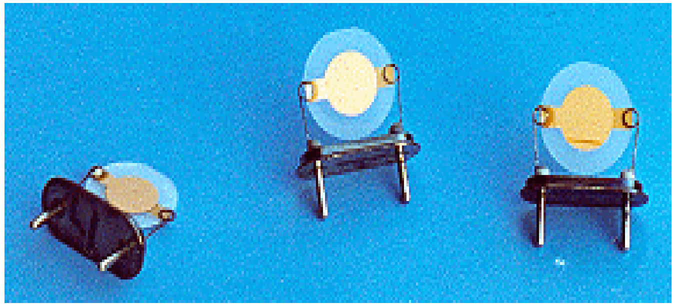
1: Overview & History

2: Sound Waves

3: Ultrasound Generation

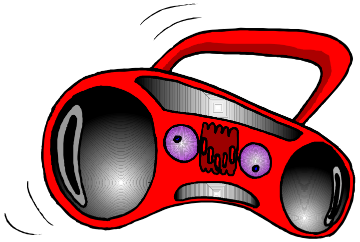
4: Ultrasound in Tissue

Sources of Sound Waves

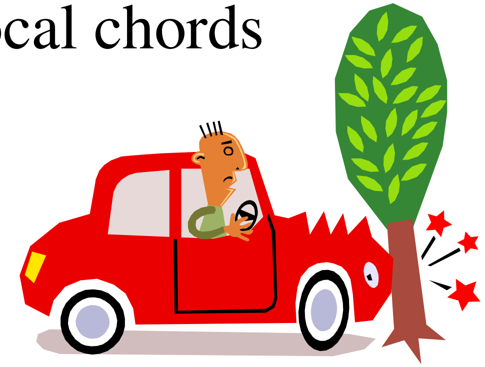


Piezoelectric Element

Vocal chords



Audio speaker system

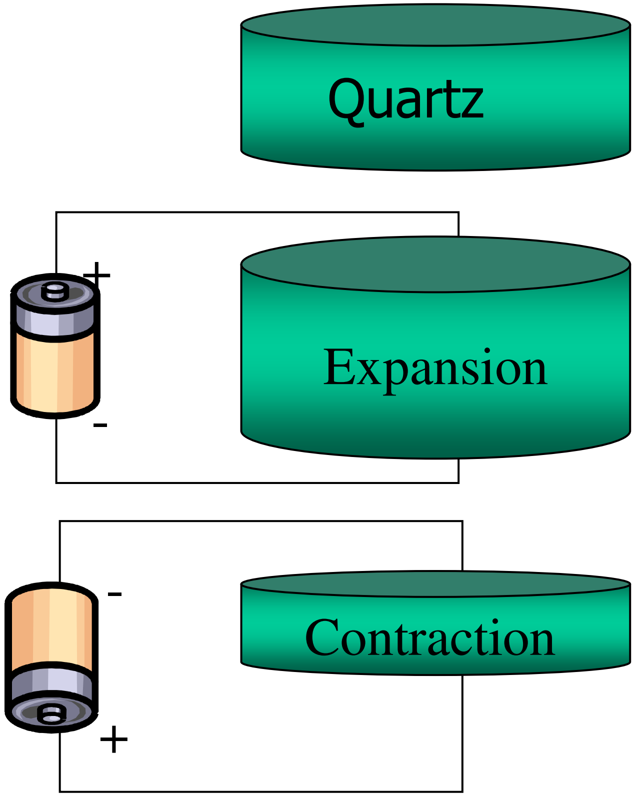


Collision!

Ultrasound Generatiom

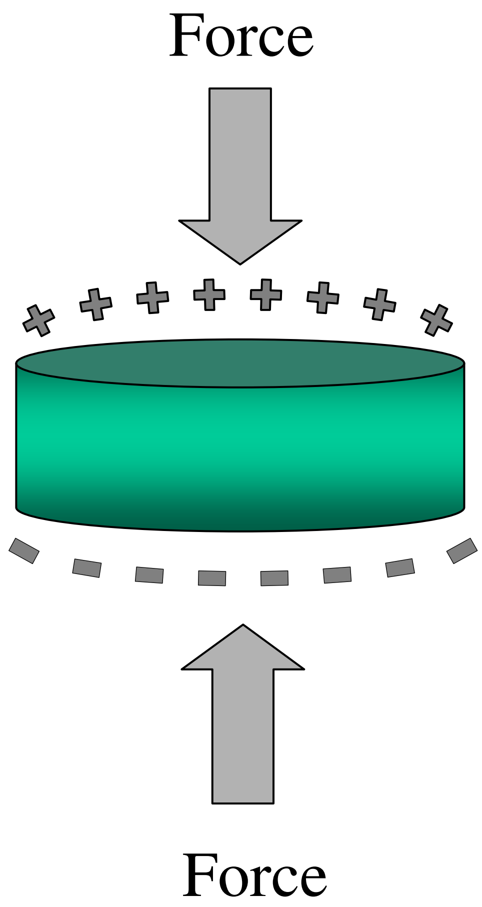
Piezoelectric effect discovered in 1880

Pierre &
Jacques Currie



Ultrasound Detection

- Apply force to piezoelectric material
- Result is electrical charge proportional to force
- The frequency of the force applied will effect the frequency with which a voltage is generated



Piezoelectric materials

- Quartz is a naturally occurring piezoelectric material.
- Lead Zirconate Titanate (PZT) is the synthetic ceramic material traditionally used for transducers.
  - Can be customised according to the specialist properties required.

Transducer

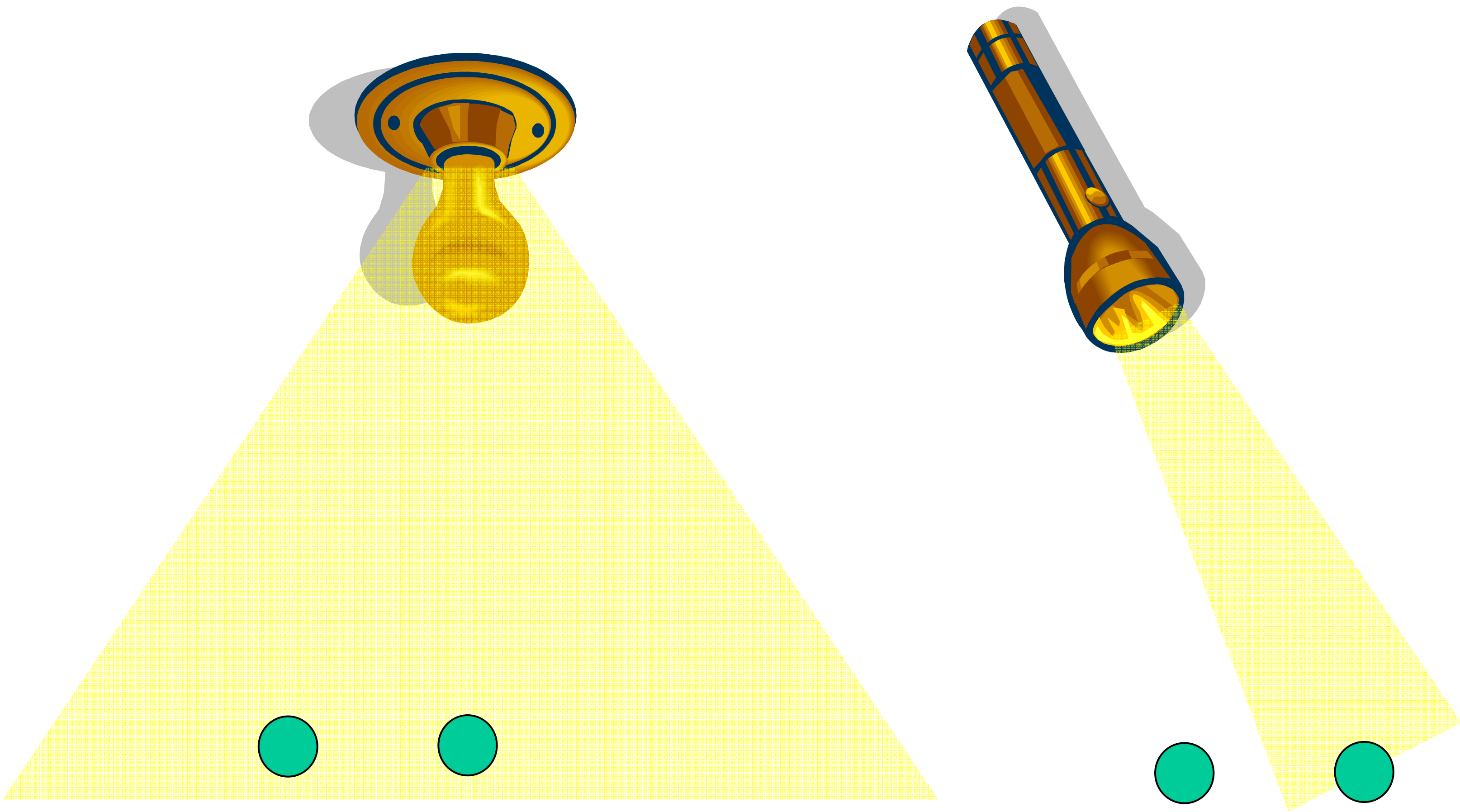
- …any device that transforms one kind of energy into another
  - E.g. electrical to mechanical

- The information obtained from ultrasound scanning depends in large part on the beam characteristics, which in turn are governed by transducer design.

"Ultrasound transducers"

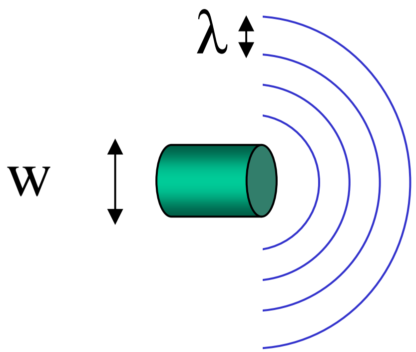
Franco Bertora

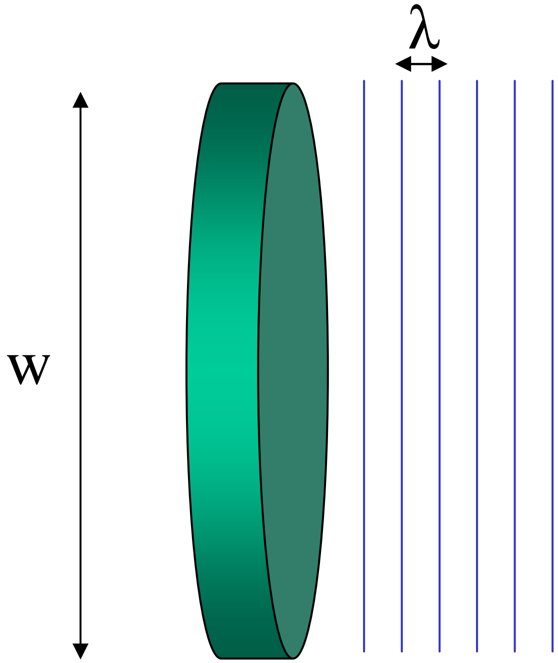
Beam Shape



Beam Shape

Diffraction





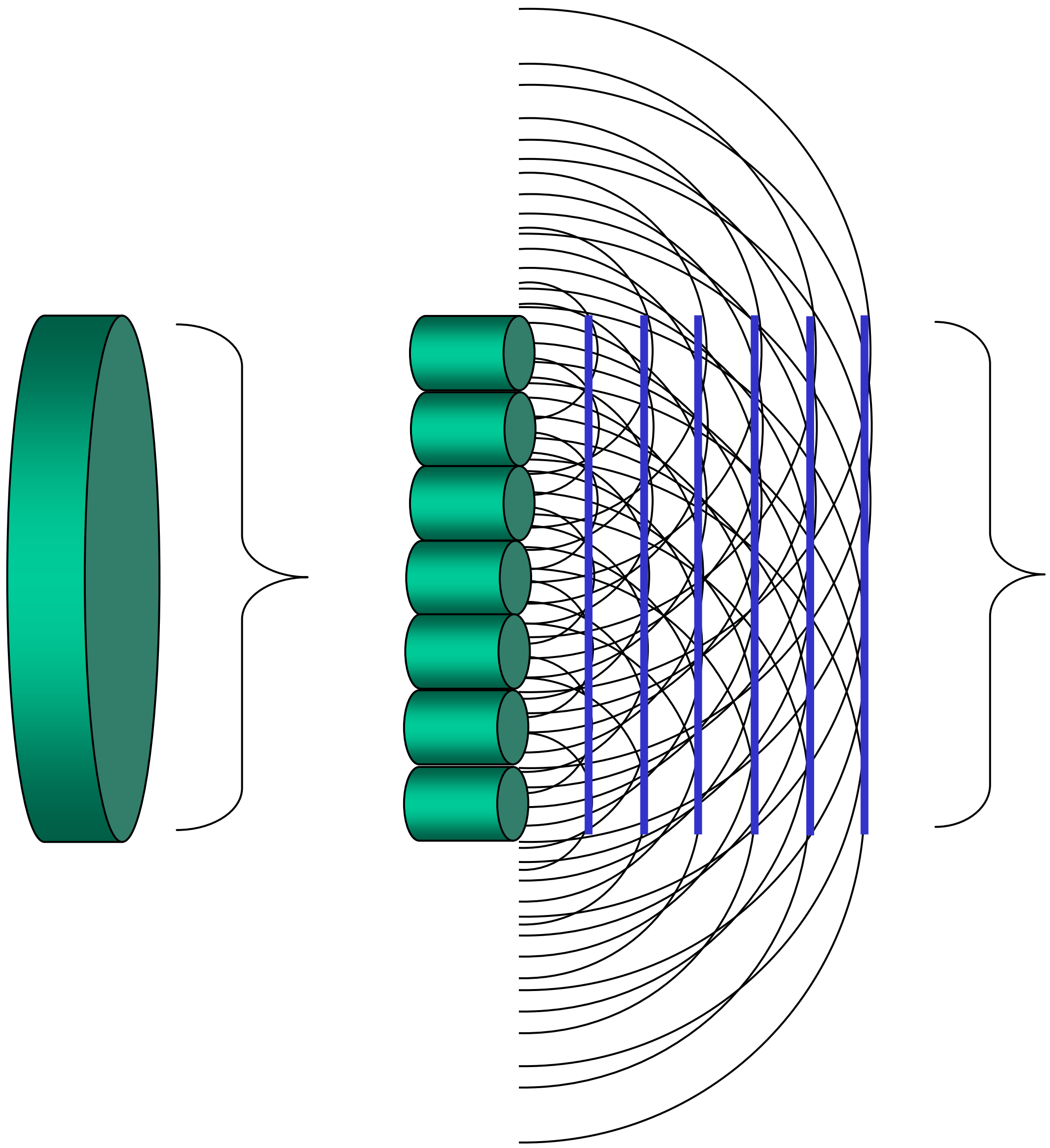
directional

$W << \lambda$
Small point source

$W >> \lambda$

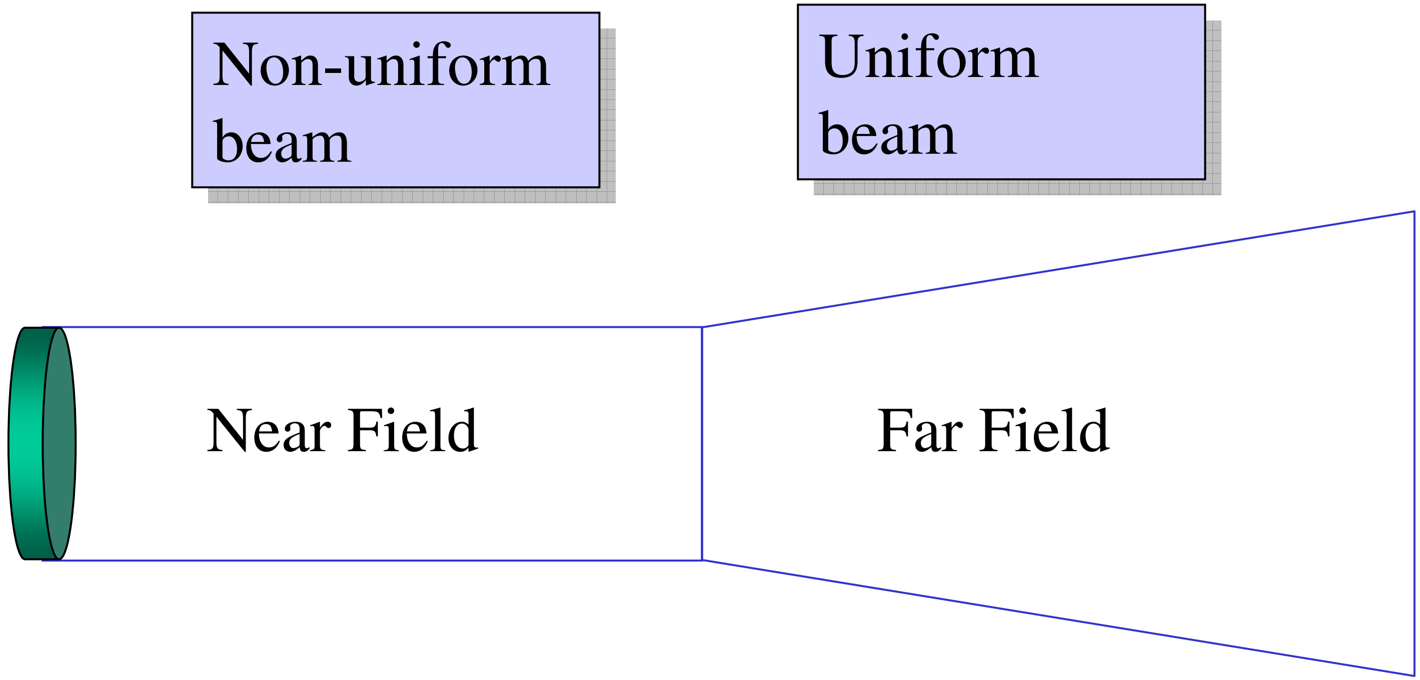
Spherical wave

Plane wave

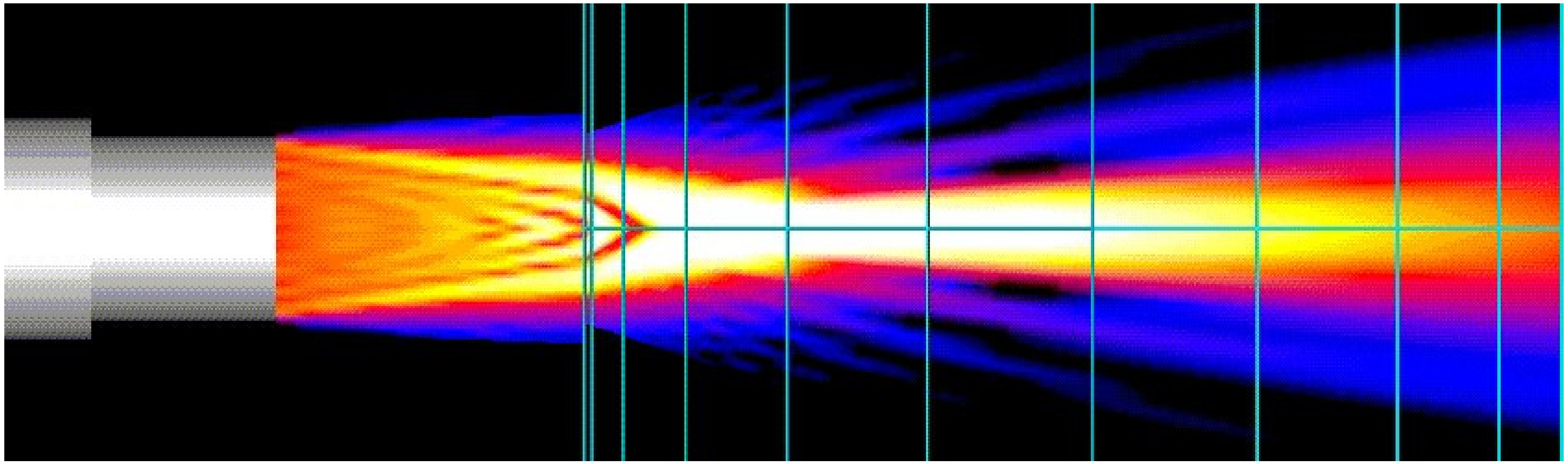


Constructive and destructive interference, in accordance with Huygens' principle

Plane Disc Source

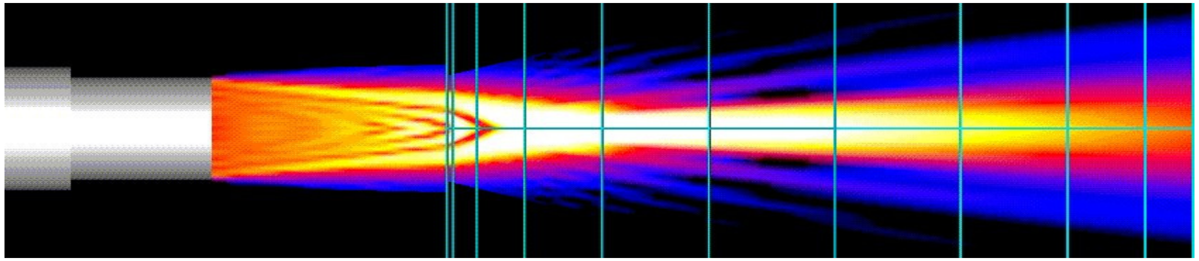


Ultrasound beam from a plane disc source

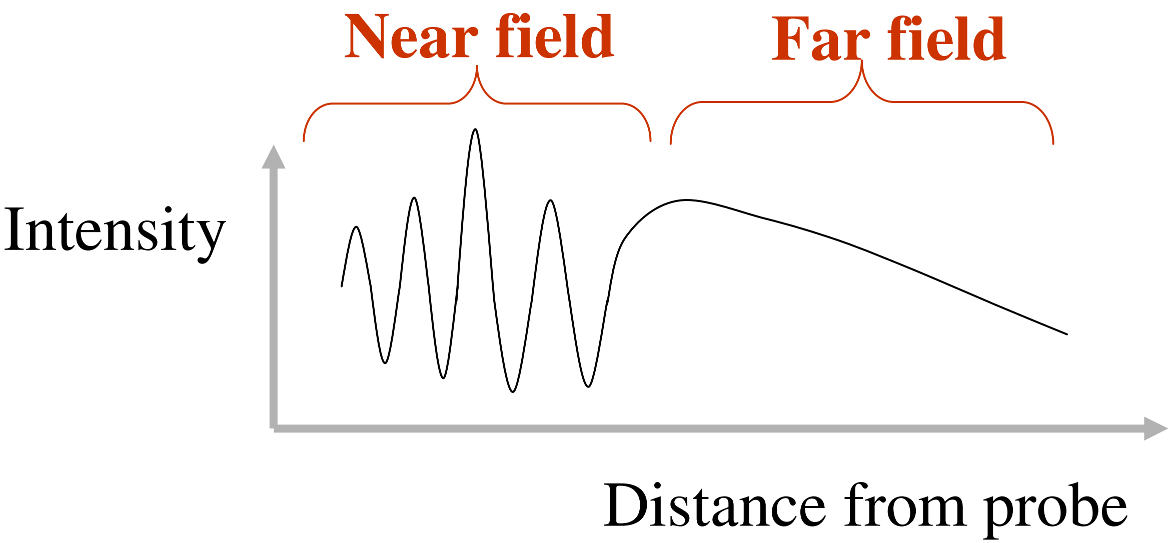


Continuous beam, single frequency

Intensity Variation



Intensity varies in space and time



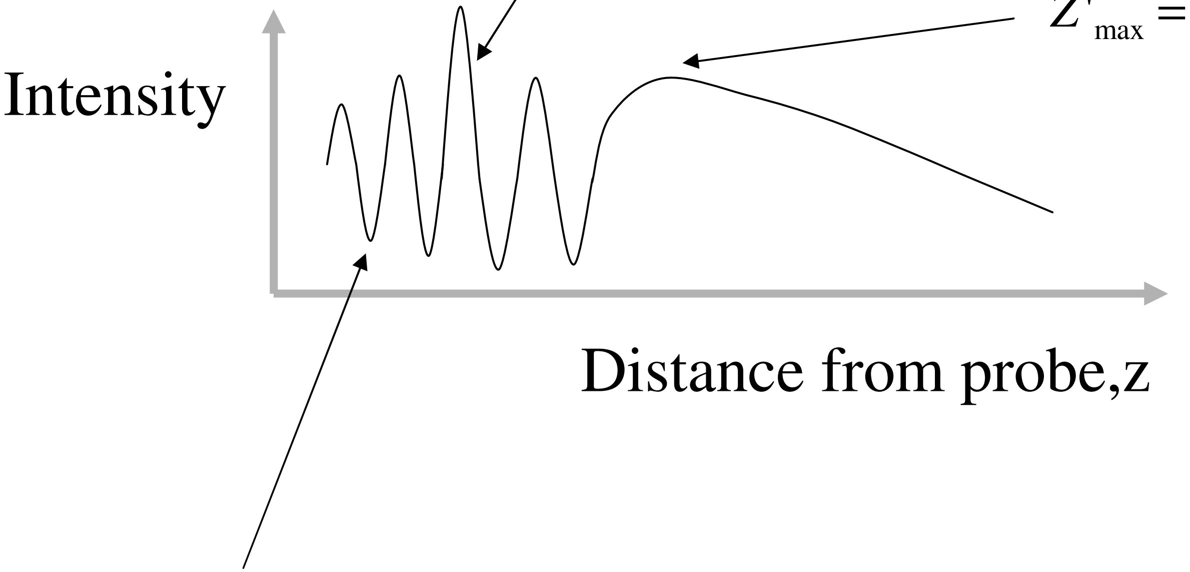
Solve a 3D geometrical problem

$$\frac{I_z}{I_0} = \sin^2 \frac{\pi}{\lambda} \left[\left(r^2 + z^2 \right)^{1/2} - z \right]$$

$$Z_{max} = \frac{4r^2 - \lambda^2 (2m+1)^2}{4\lambda(2m+1)}$$

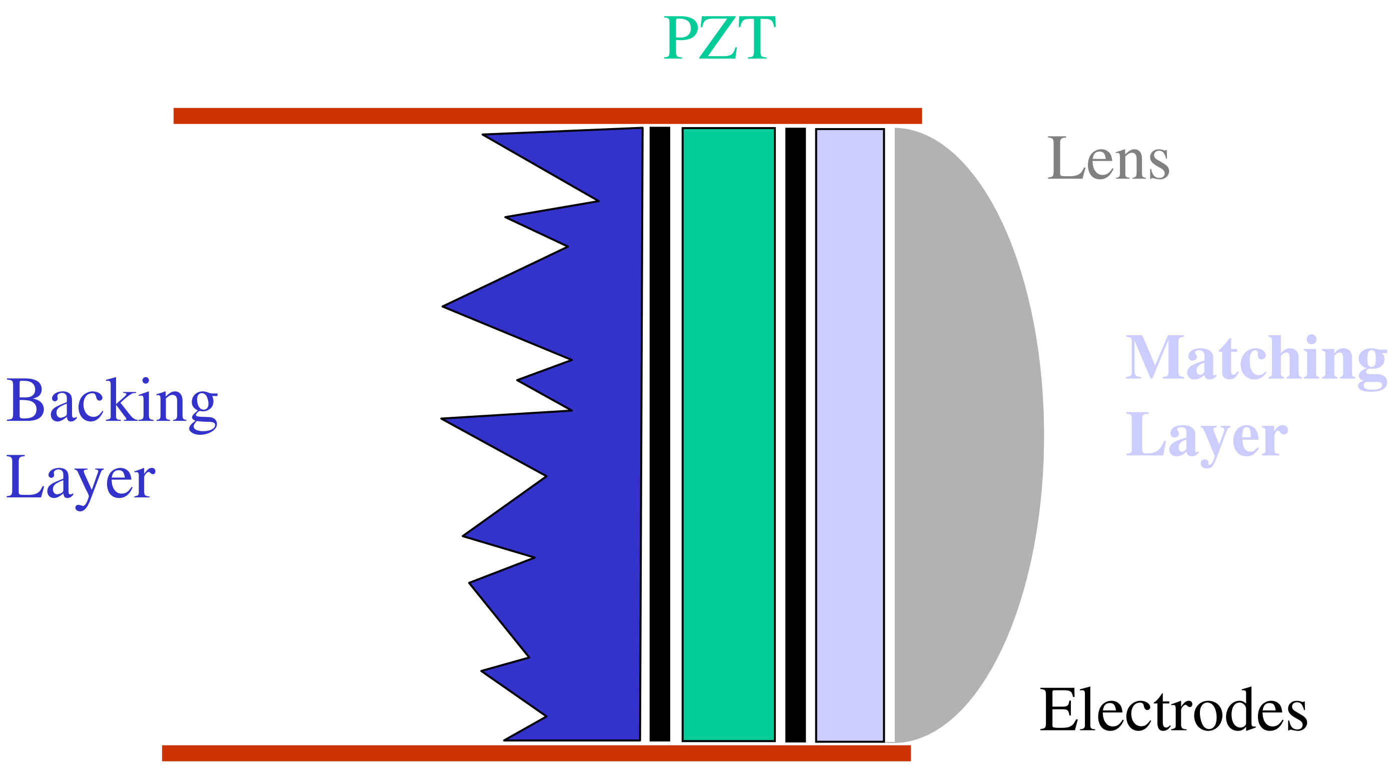
$$Z'_{max} = \frac{r^2}{\lambda}$$

Near Field length



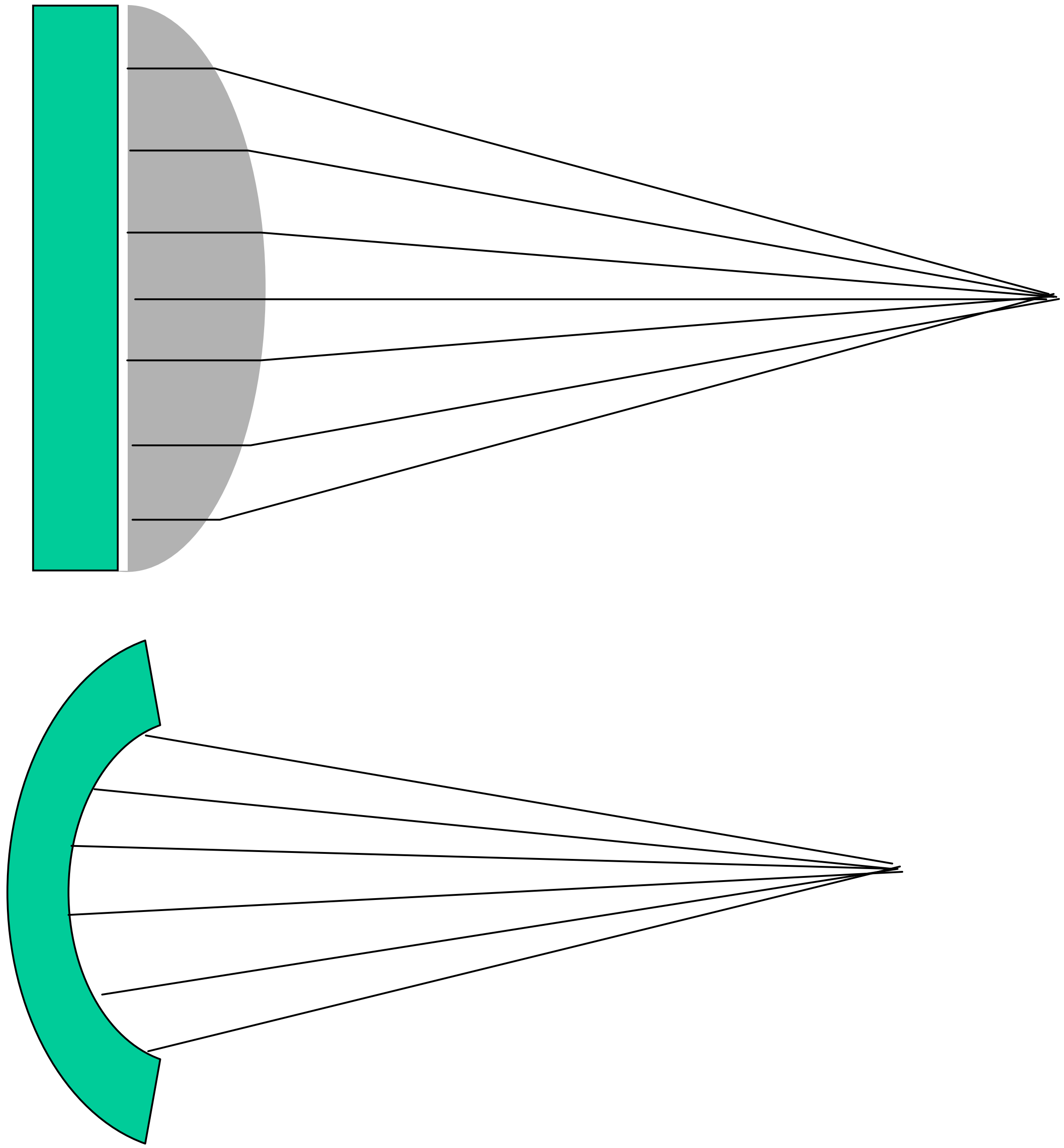
$$Z_{min} = \frac{r^2 - \lambda^2 n^2}{2n\lambda}$$

Component elements



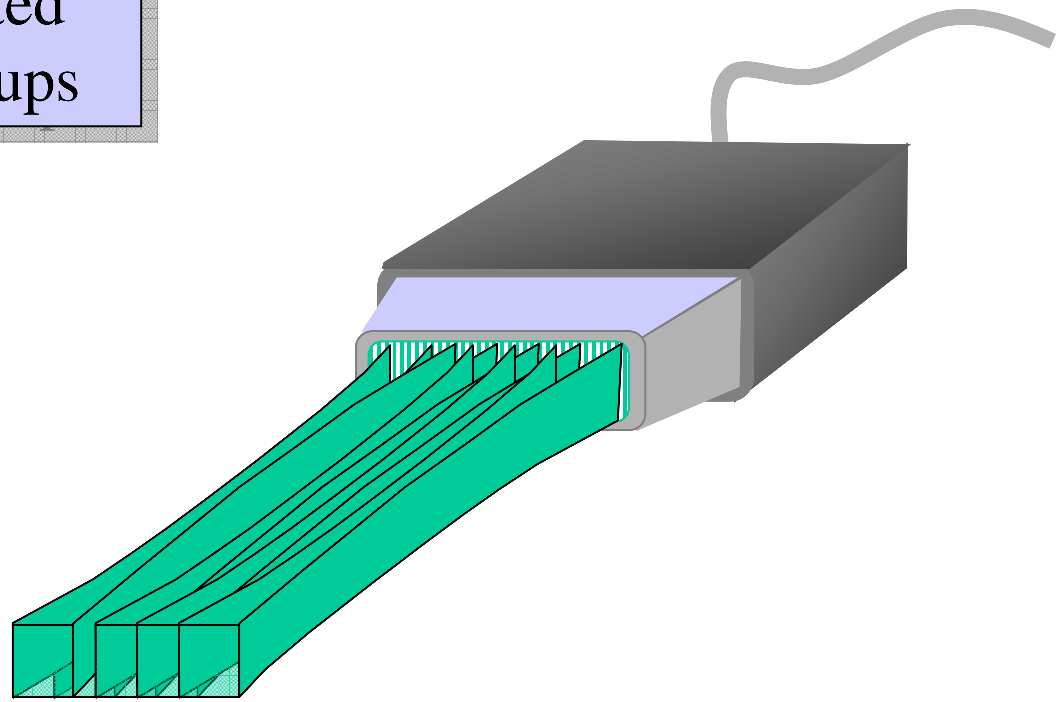
Lens

- A narrow ultrasound beam is desirable to allow closely spaced targets to be resolved.
- Improvement to the beam can be made by focussing
- An acoustic lens attached to the face of a flat surface produces a curved wavefront by refractions at its outer surface.



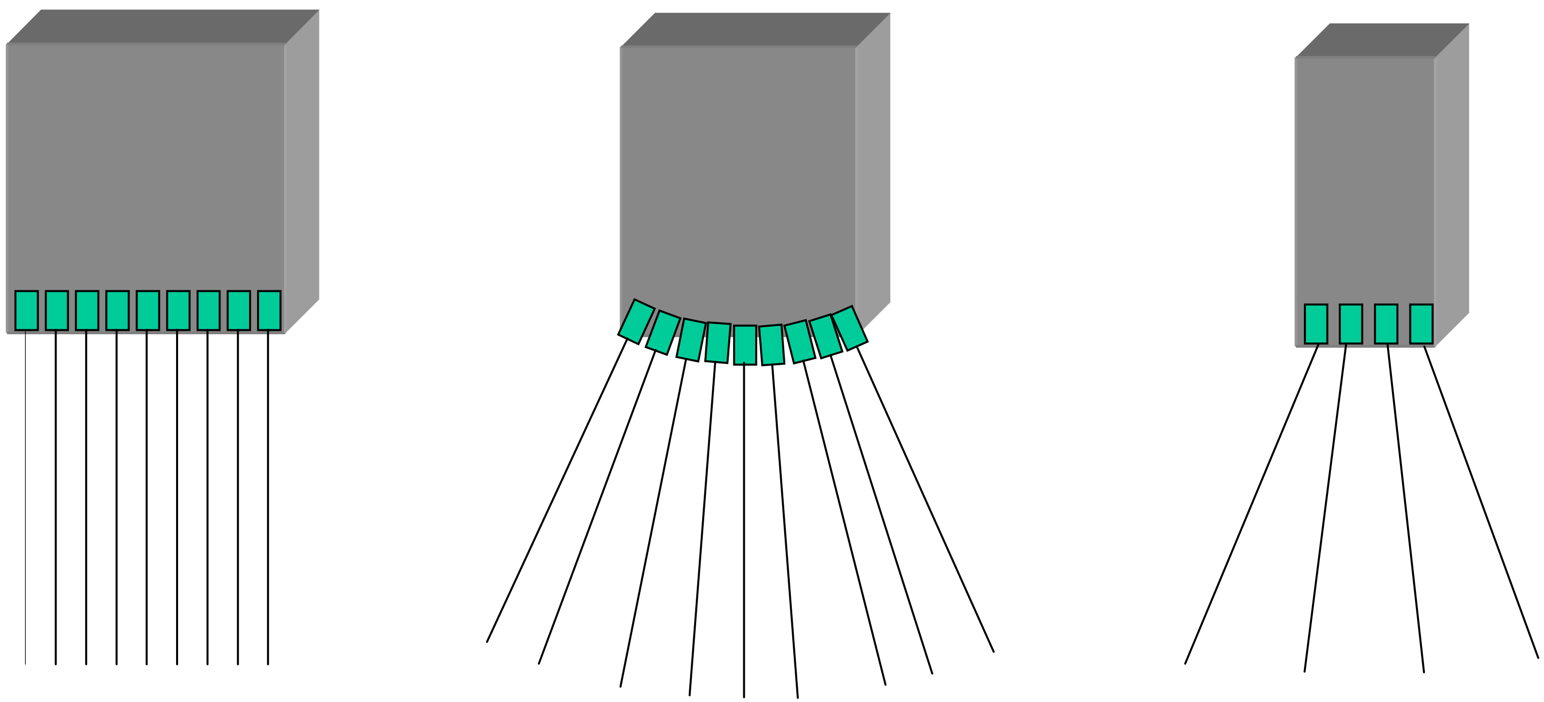
Multi-Element Linear Array

Elements can be excited individually or in groups

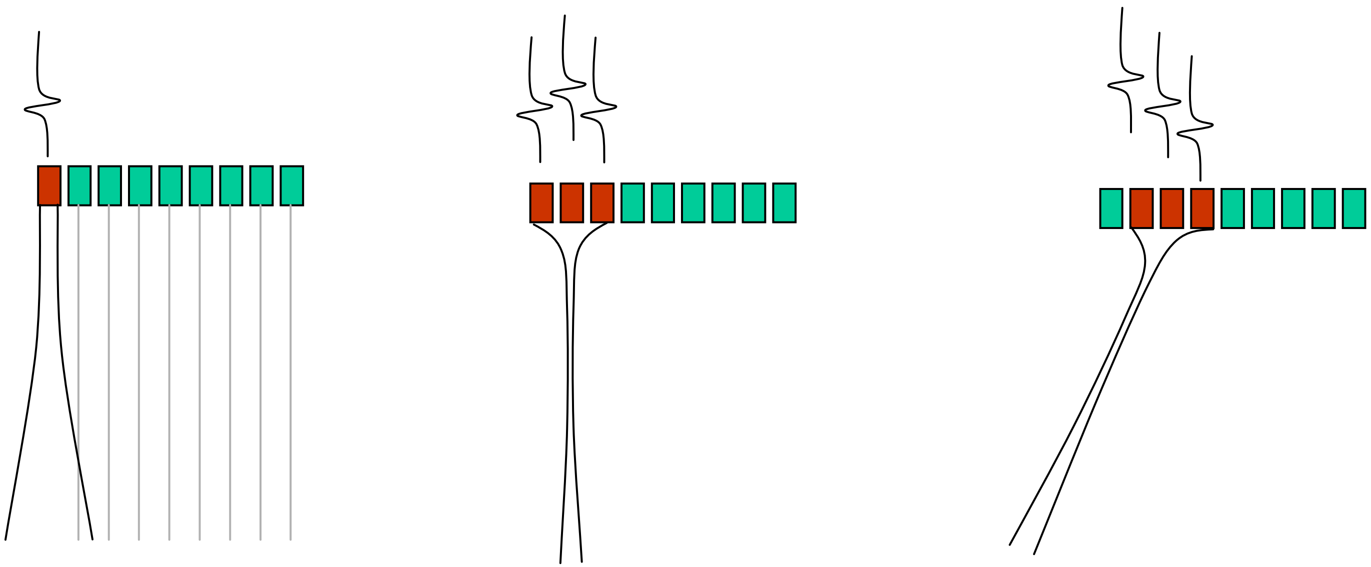


Scan lines

Different shapes & sizes



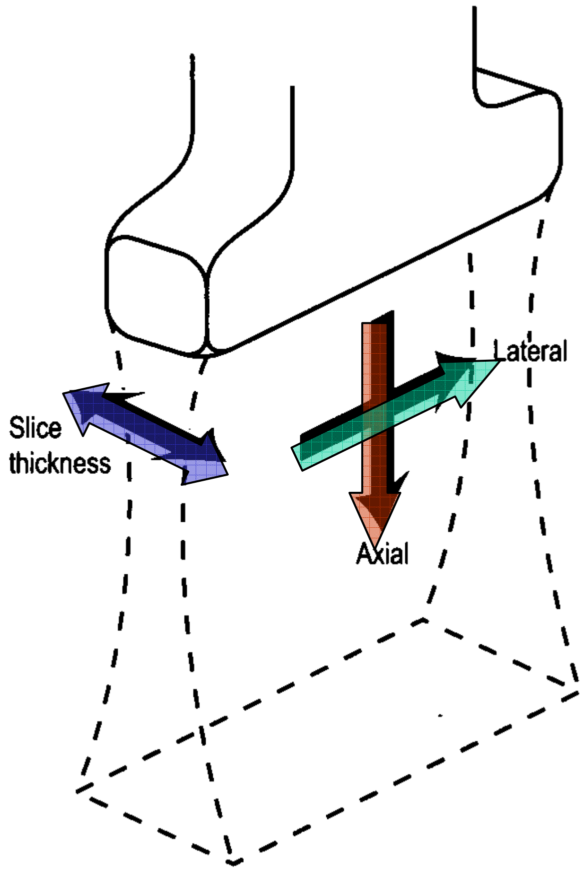
Electronic Beam Steering



Imaging Resolution

- Spatial Resolution
- Temporal Resolution
- Contrast Resolution

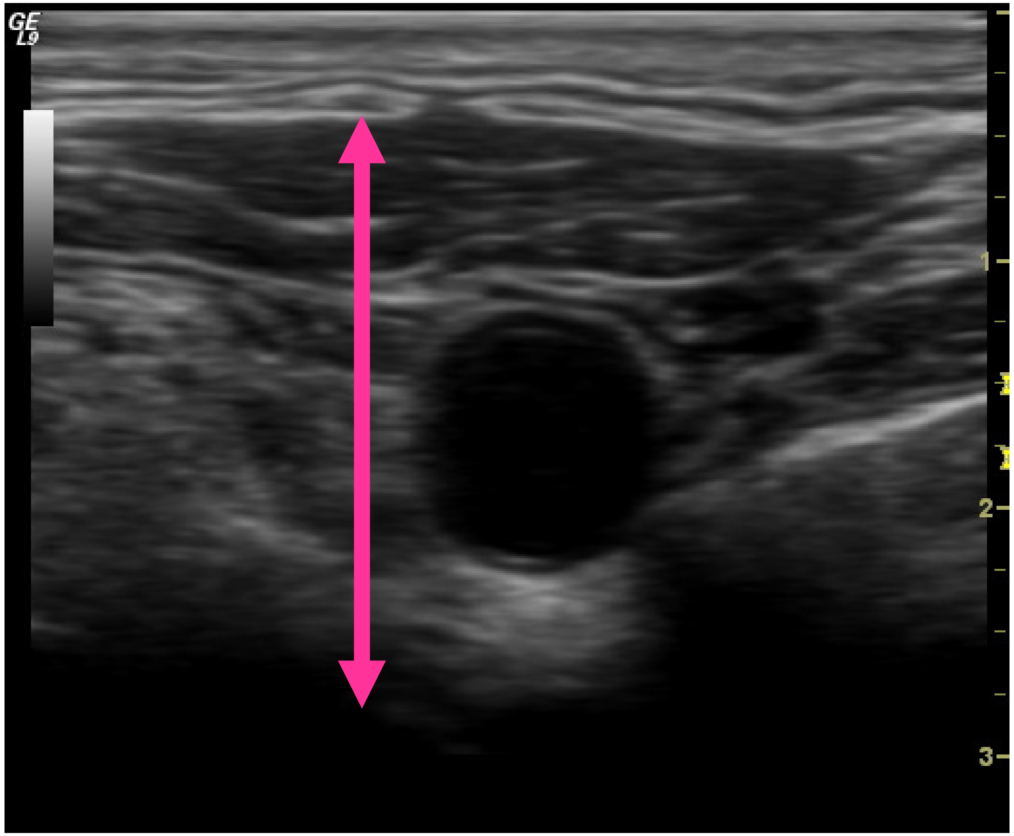
Spatial Resolution



Spatial (in space)

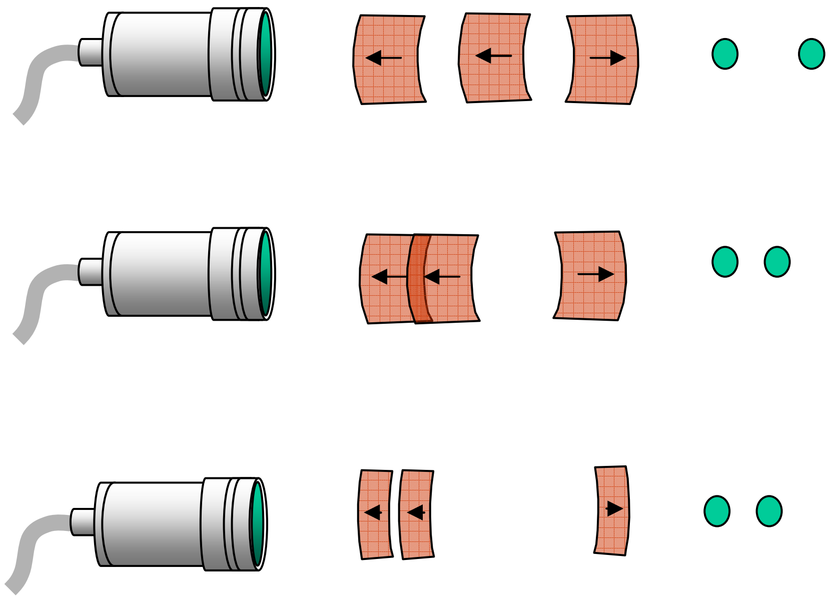
- axial (along the beam)
- lateral (across the beam)
  - azimuth (in the scan plane)
  - elevation or slice thickness (perpendicular to the scan plane)

Axial Resolution



Axial Resolution

- The minimum reflector spacing **along the axis of the ultrasound beam** that results in separate, distinguishable echoes on the display.



Axial Resolution

Pulse length =number of cycles x λ

- Example 3MHz transducer

$$\lambda = \frac{c}{f} = \frac{1540 m/s}{3{,}000{,}000 Hz} = 0.5 mm$$

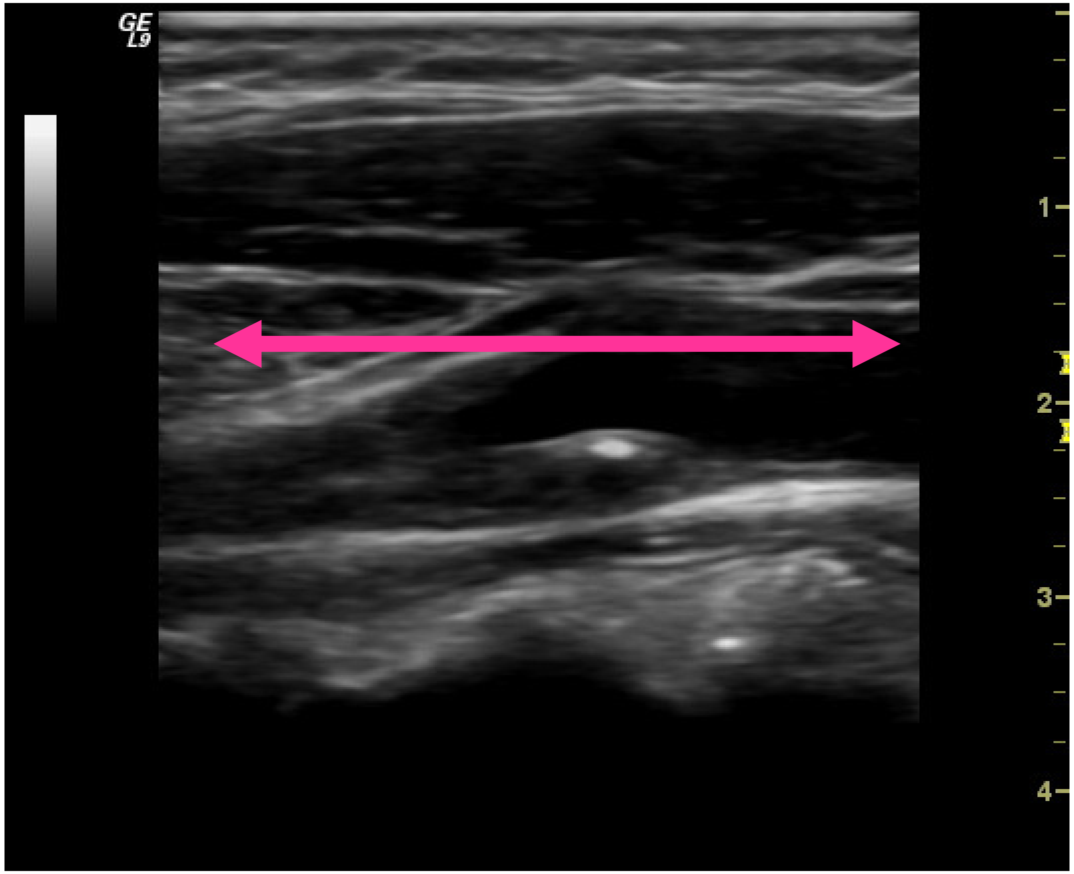
r_a =3 x 0.5 = 1.5 mm

- Example 10MHz transducer

$$\lambda = \frac{c}{f} = \frac{1540 m/s}{10{,}000{,}000 Hz} = 0.15 mm$$

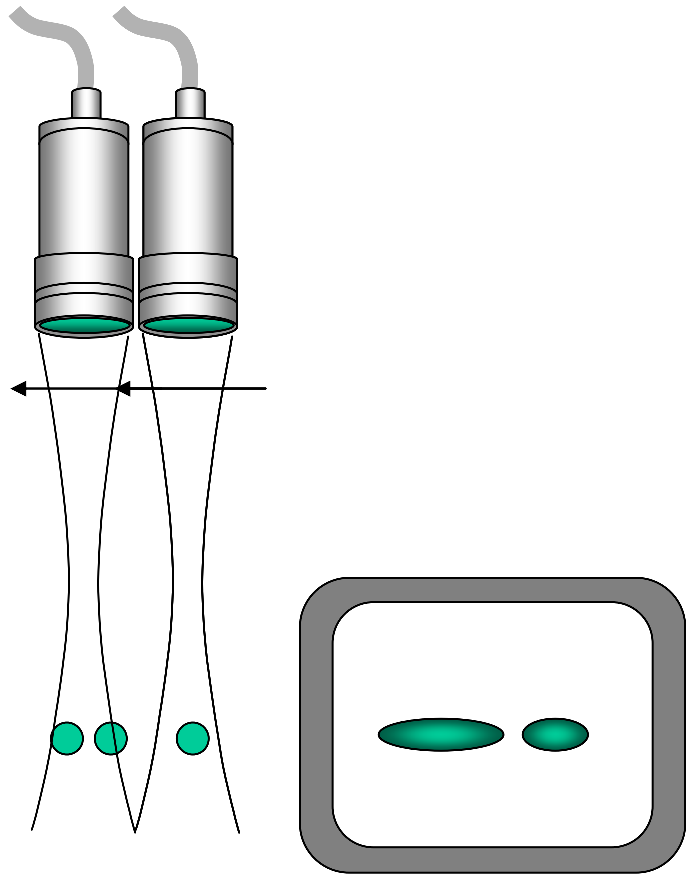
r_a =3 x 0.15 = 0.45 mm

Lateral Resolution



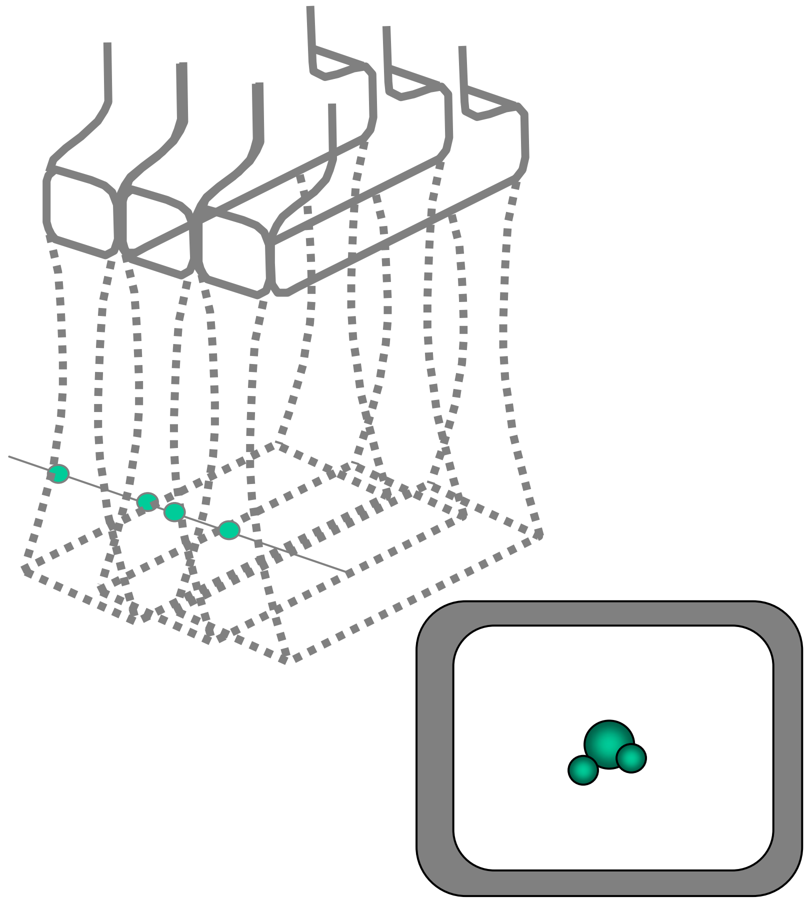
Lateral Resolution

- The ability to distinguish two closely spaced reflectors that are positioned **perpendicular to the axis** of the ultrasound beam.



Elevational Resolution (slice thickness)

- Works in a direction perpendicular to the image plane.
- Dictates the thickness of the section of tissue that contributes to echoes visualised on the image.

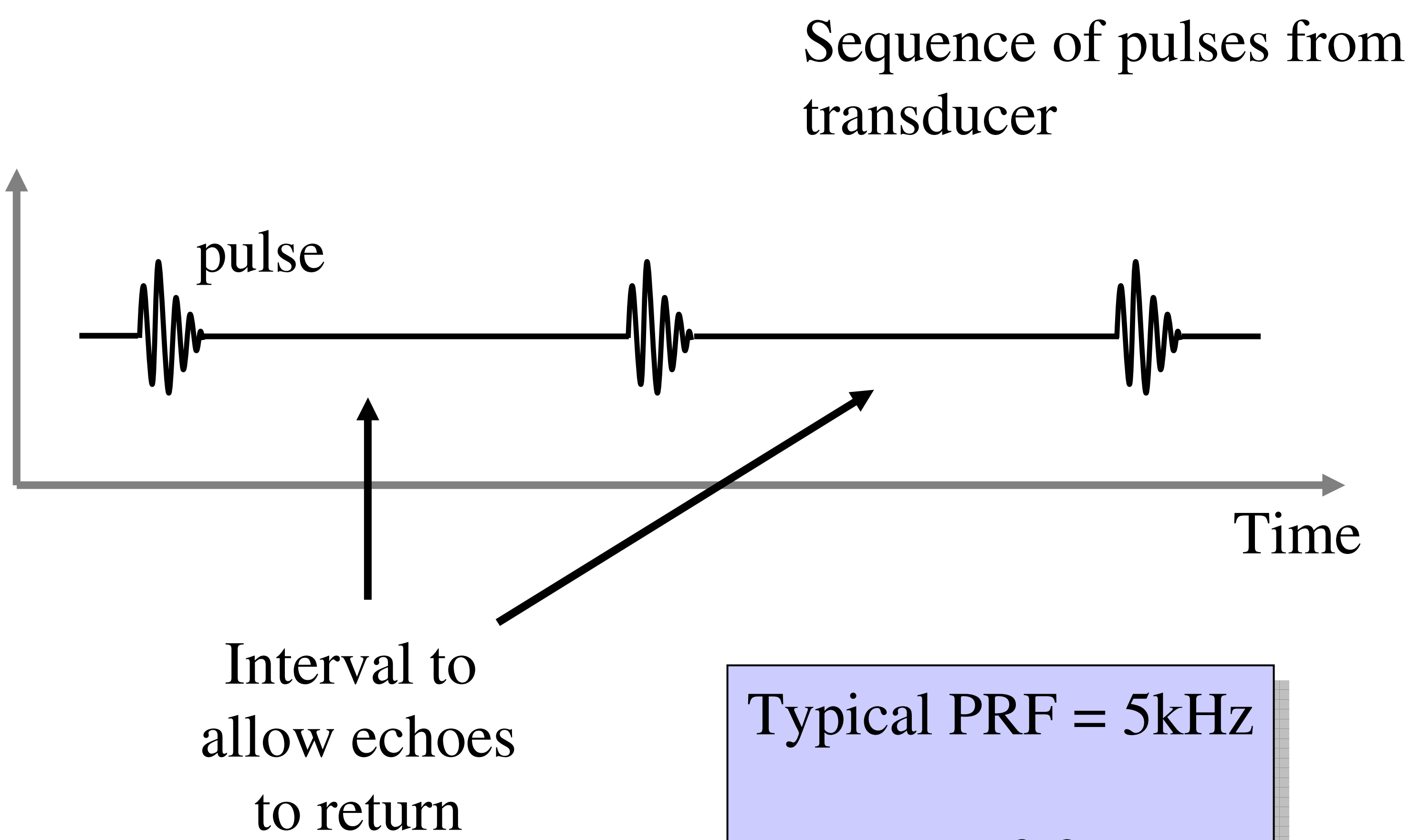


Slice Thickness Resolution

Temporal Resolution

- The time interval between pulses
  - limits the temporal resolution
  - it is usually set so that there is sufficient time for the most distant echo to return to the transducer before the next pulse is launched

Temporal Resolution

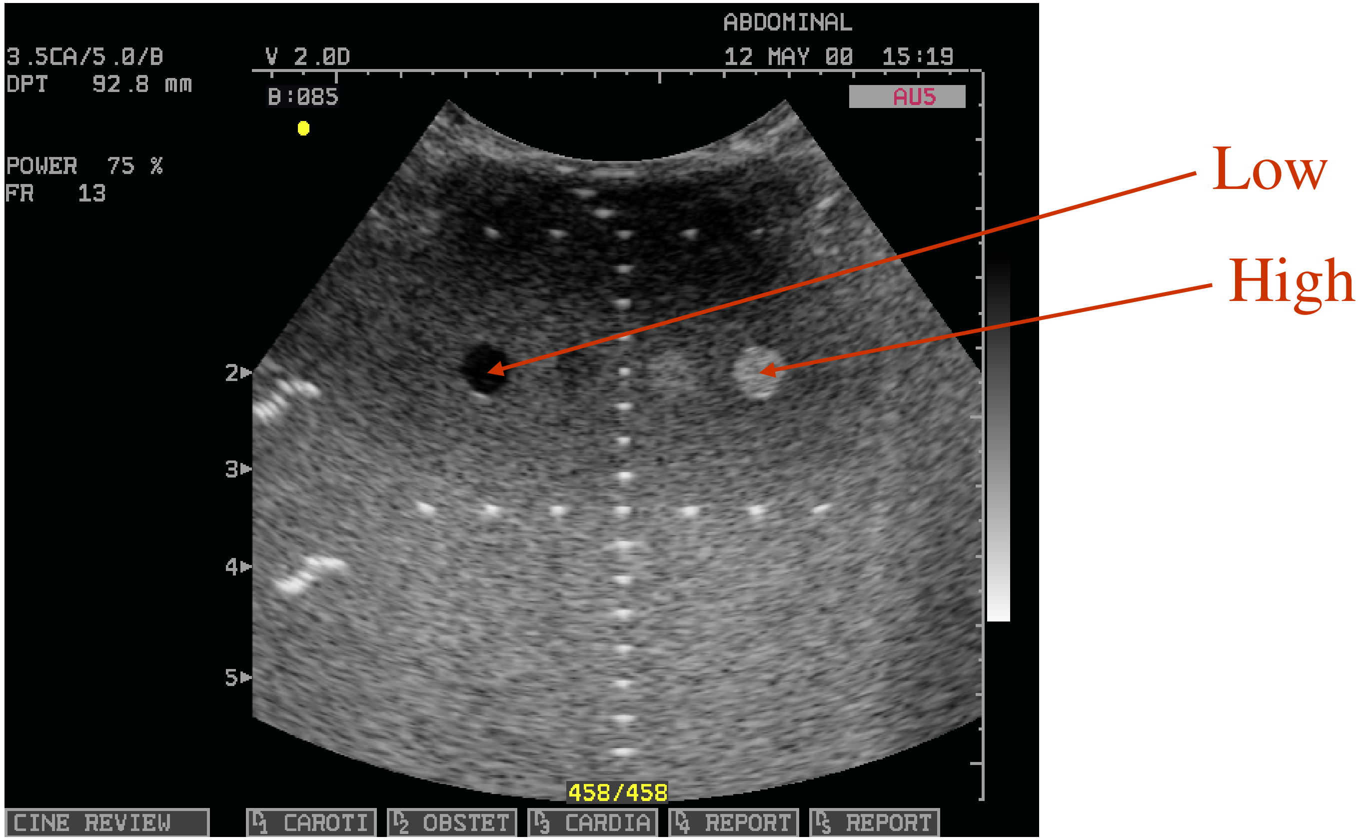


Typical PRF = 5kHz

T_{PRF} = 0.2 ms

Contrast Resolution

The ability to display regions of differing echo size



Basic Principles of Ultrasound

1: Overview & History

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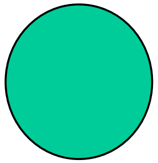
3: Ultrasound Generation

4: Ultrasound in Tissue


Speed of Sound
Impedance
Reflection
Refraction
Attenuation
Non-linear effects
Safety

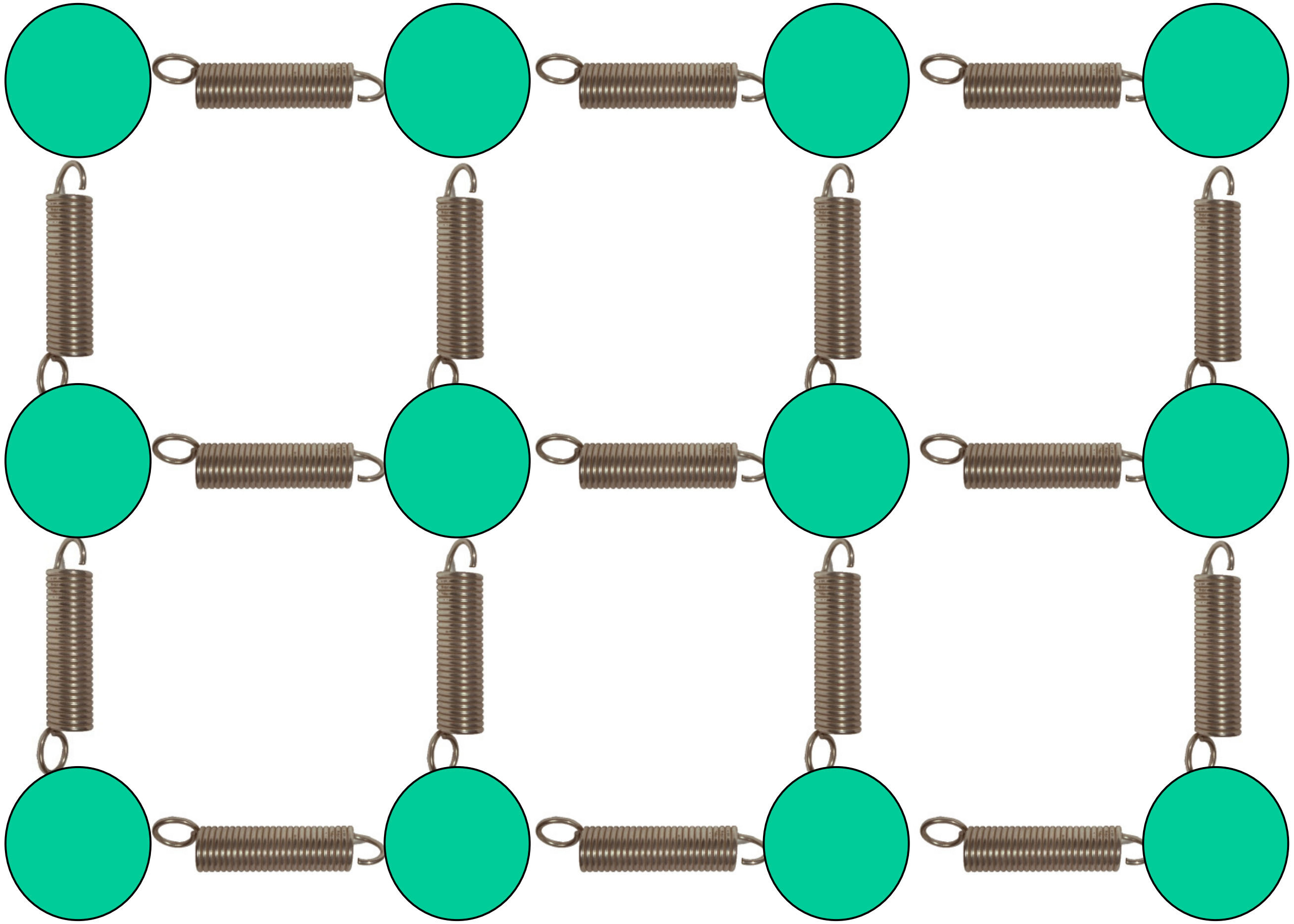
Matter

- It is helpful, for ultrasound purposes, to imagine that matter is composed of
  - tiny particles



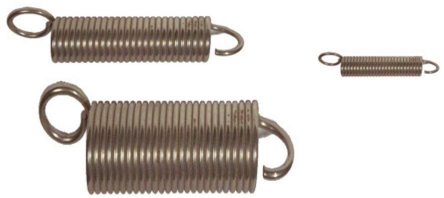
  - joined together by springs

Matter

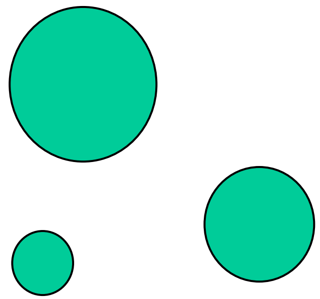


Properties

- Stiffness of substance K (bulk modulus)
  - strength of the spring

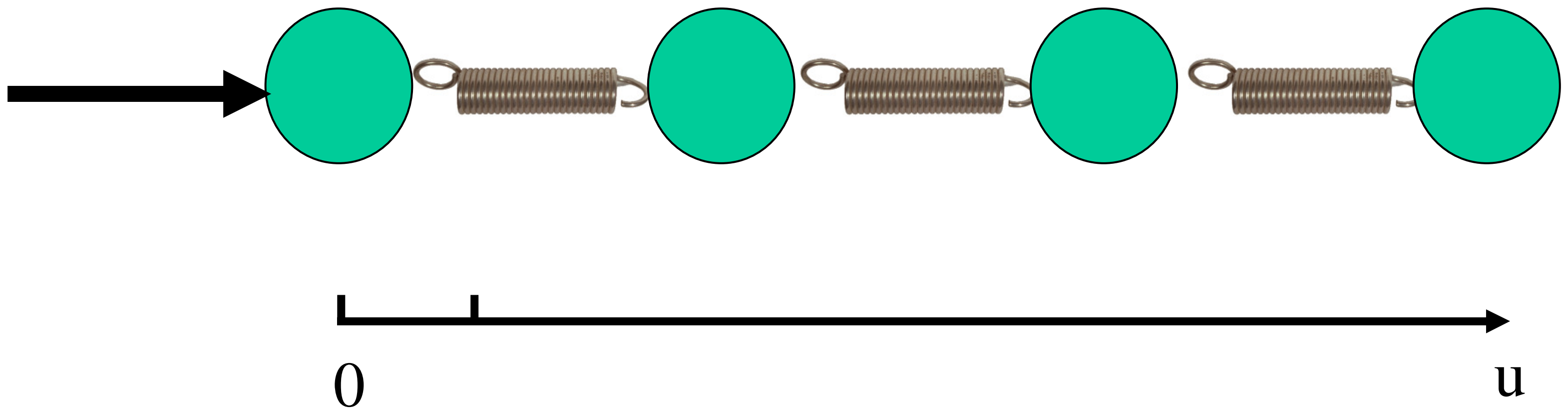


- Density of substance ρ
  - mass & separation of particles

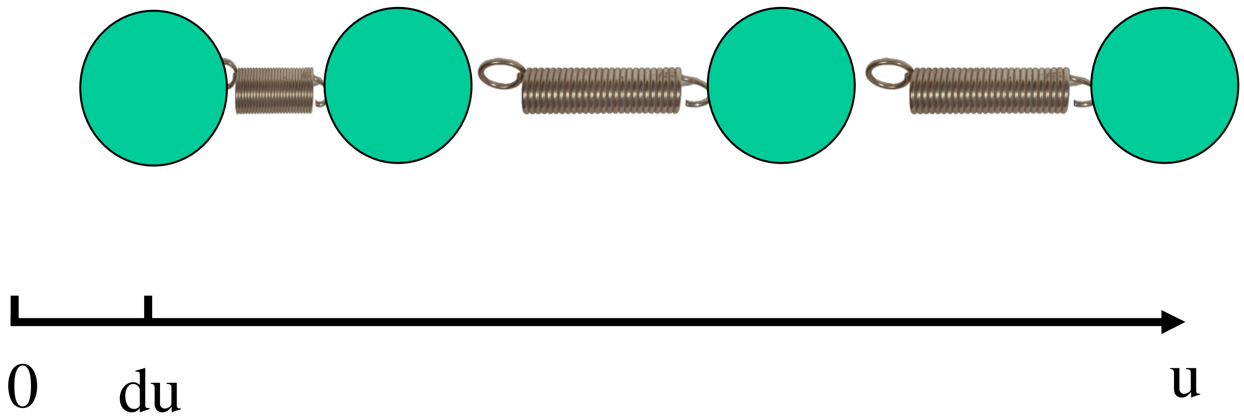


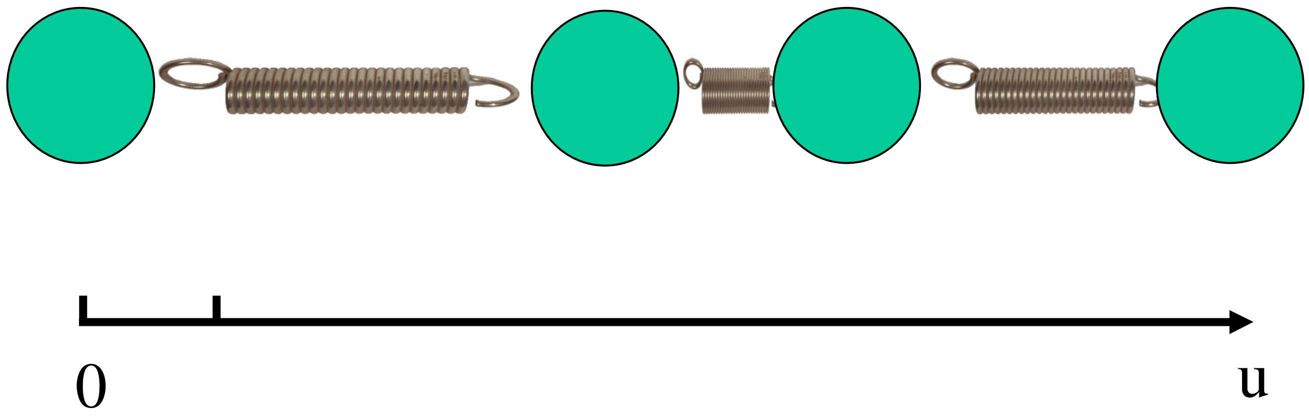
Movements

- Each particle is connected to each of its neighboring particles by ‘springs’
- A single movement of ONE particle will move all the others
- Repetitive movements will move all the others repetitively - but after a time delay


0
u

$$v = \frac{du}{dt}$$ particle velocity

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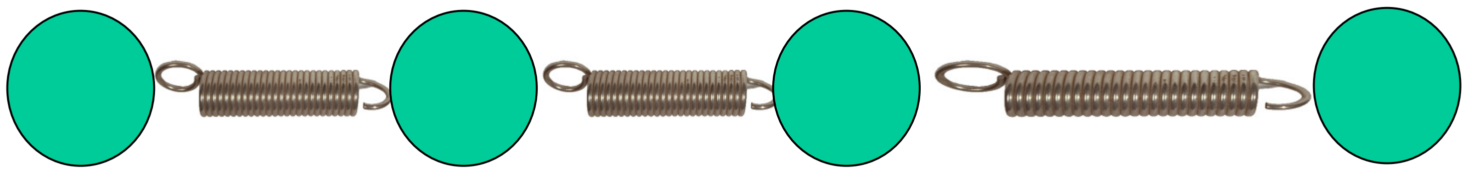
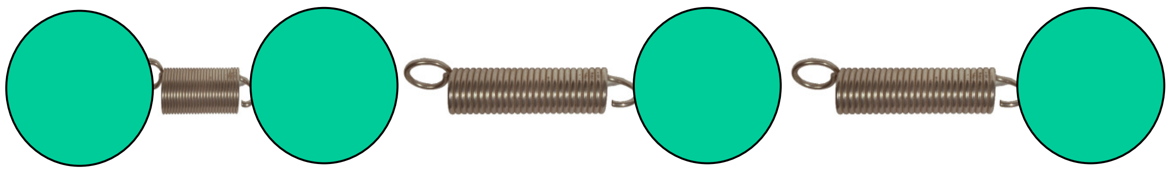
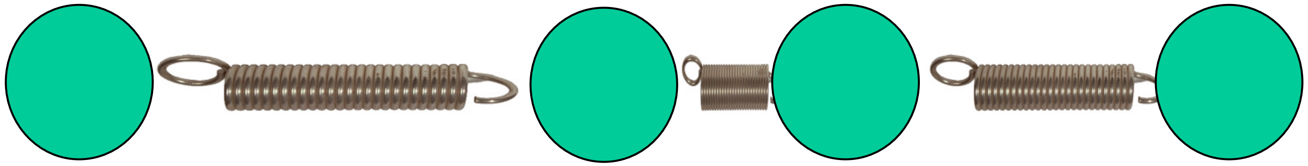
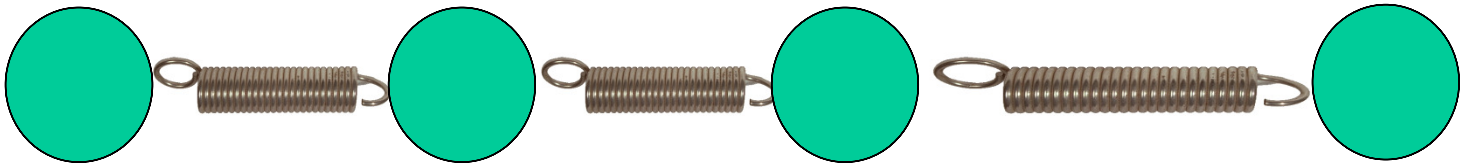
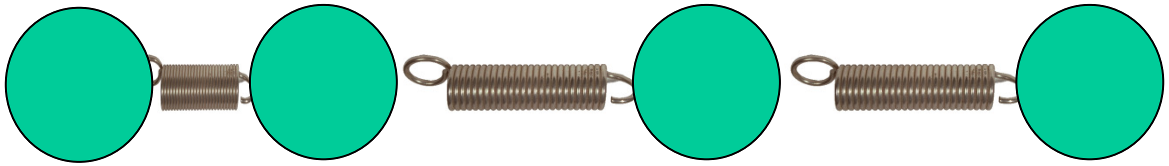
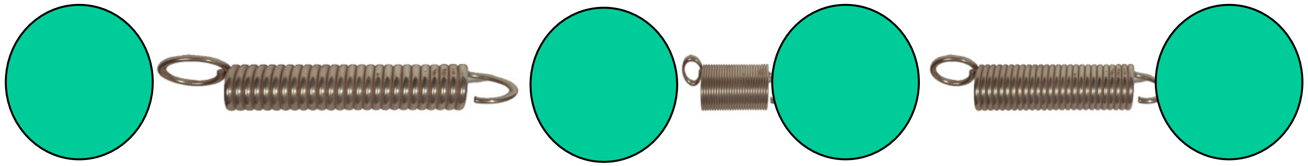


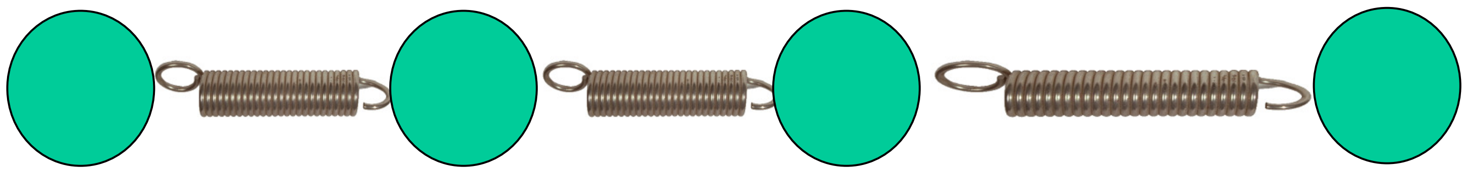












X

Speed of Sound

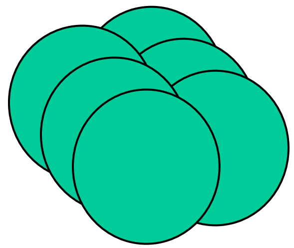
- Low density and high stiffness
  → high speed of sound

- High density and low stiffness
  → low speed of sound

Mathematically…

$$c = \sqrt{\frac{k}{\rho}}$$

Bulk modulus 

Density 

Speed of Sound

Programme the ultrasound machine with...

- Air 330m/s
- Water 1480m/s
- Fat 1460m/s
- Blood 1560m/s
- Muscle 1600m/s
- Bone 4060m/s

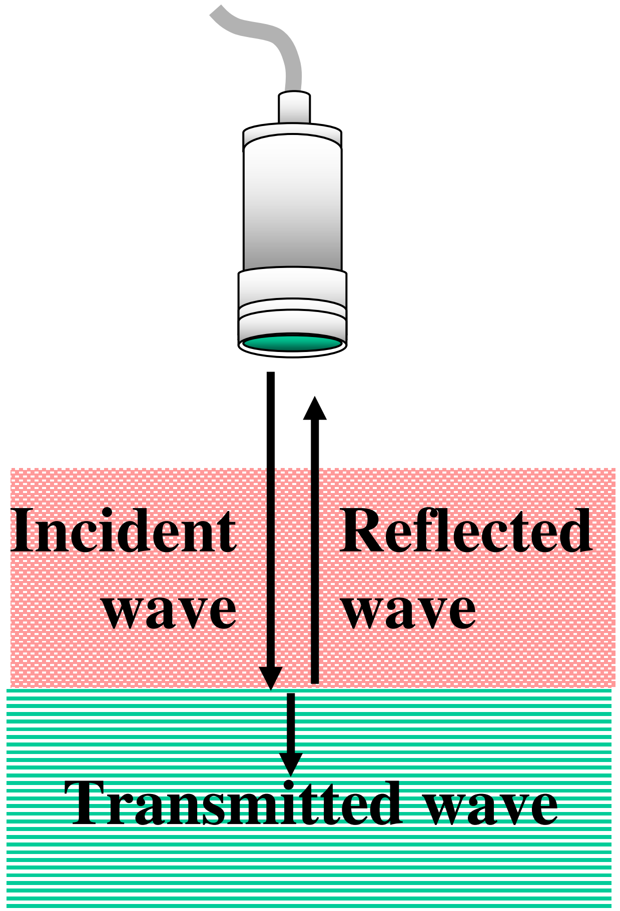
(Fat, Blood, Muscle:) Average soft tissue value = 1540m/s

This can lead to small errors in the estimated distance travelled because of the variation in the speed of sound in different tissues.


Speed of Sound
Impedance
Reflection
Refraction
Attenuation
Non-linear effects
Safety

Reflection at Boundaries

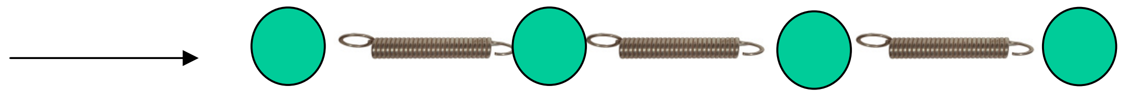
- At the boundary between tissues ultrasound is partially reflected
- The relative proportions of the energy reflected and transmitted depend on the <u>acoustic impedance</u> between the two materials



Acoustic Impedance

Small masses

Weak springs

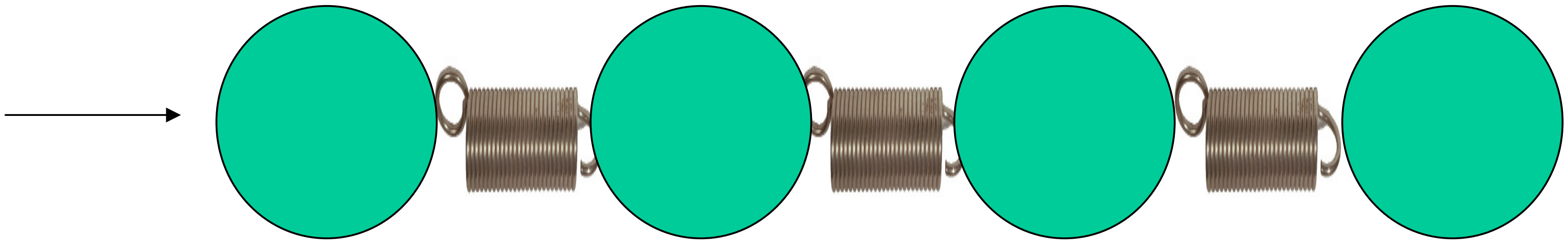


Low impedance

Acoustic Impedance

Large masses

Strong springs

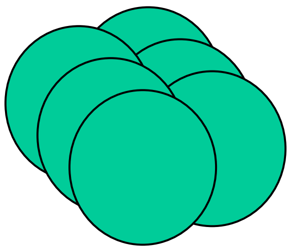


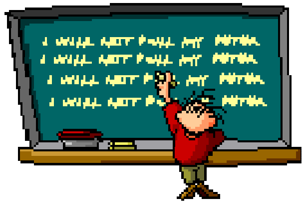
High impedance

Mathematically

$$z = \sqrt{\rho k}$$

Density x Bulk modulus





The Proof…

- Acoustic Impedance analogous to electrical resistance.

- So using Ohm's law

  P = local pressure

  v = local particle velocity

$$z = \frac{P}{v}$$

Acoustic Impedance

• Air	0.0004	x 10^6 rayls
• Lung	0.18	x 10^6
• Fat	1.34	x 10^6
• Water	1.48	x 10^6
• Blood	1.65	x 10^6
• Muscle	1.71	x 10^6
• Skull Bone	7.80	x 10^6

Similar Values (Fat, Water, Blood, Muscle)


~~Speed of Sound~~
~~Impedance~~
Reflection
Refraction
Attenuation
Non-linear effects
Safety

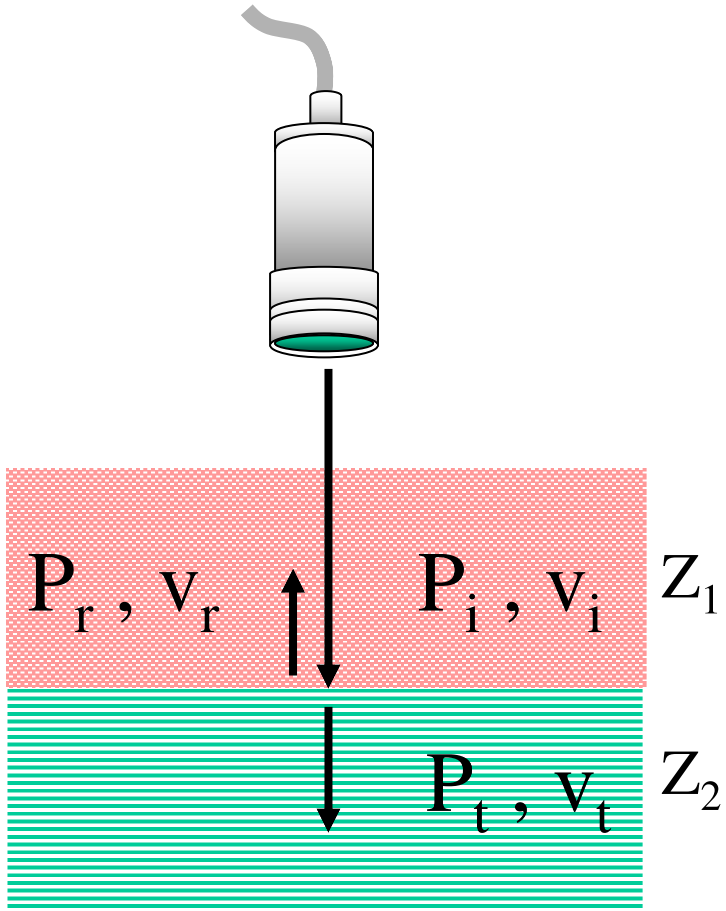
Reflection

$$P_t = P_i + P_r$$

$$v_t = v_i - v_r$$

Replace v with P/z

$$\frac{P_t}{Z_2} = \frac{P_i}{Z_1} - \frac{P_r}{Z_1}$$



$$\frac{P_t}{z_2} = \frac{P_i}{z_1} - \frac{P_r}{z_1}$$

$$P_t = \frac{z_2}{z_1} P_i - \frac{z_2}{z_1} P_r = P_i + P_r$$

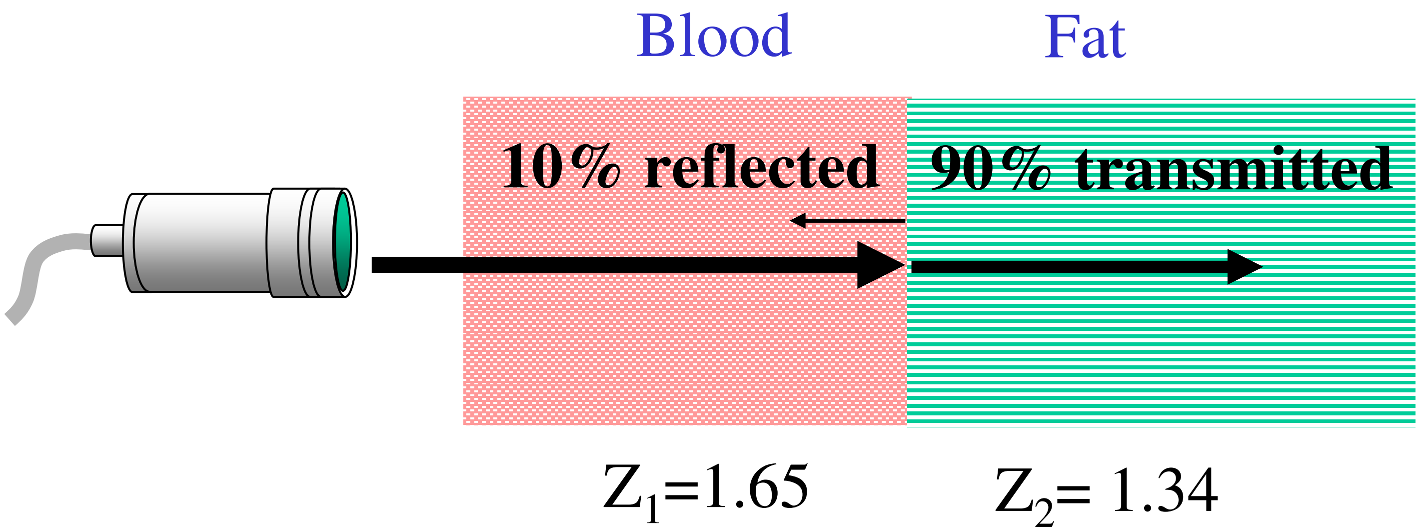
$$z_2 P_i - z_2 P_r = z_1 P_i + z_1 P_r$$

$$z_2 P_i - z_1 P_i = z_1 P_r + z_2 P_r$$

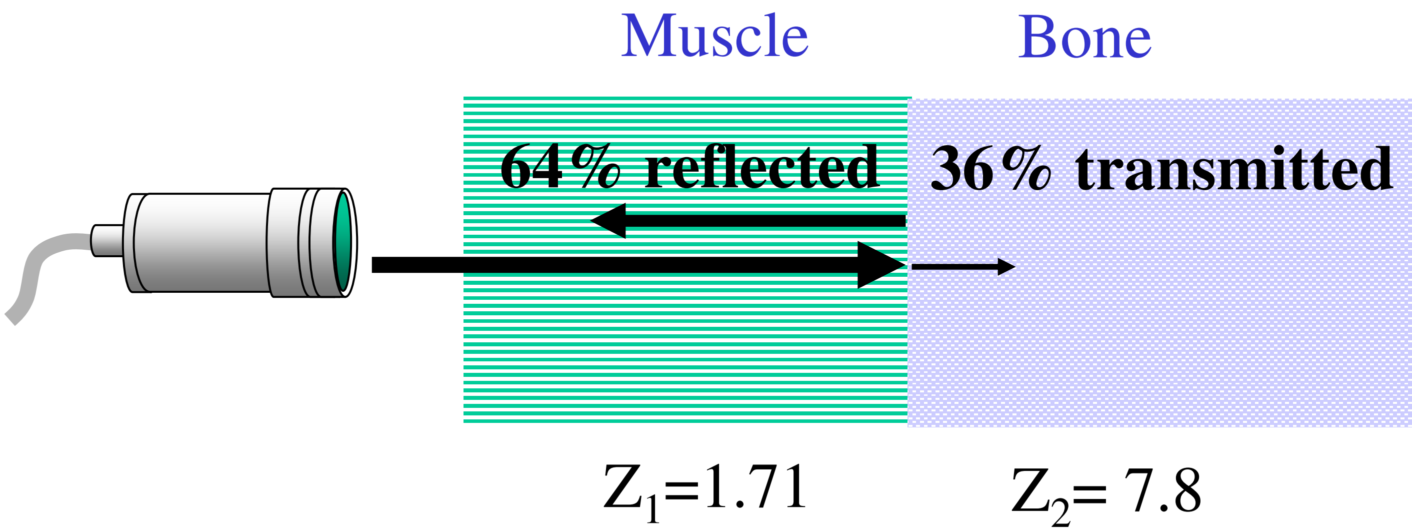
$$P_i \left(z_2 - z \right)_1 = P_r \left(z_1 + z_2 \right)$$

$$\frac{P_r}{P_i} = \frac{z_2 - z_1}{z_2 + z_1}$$

Reflection Coefficient

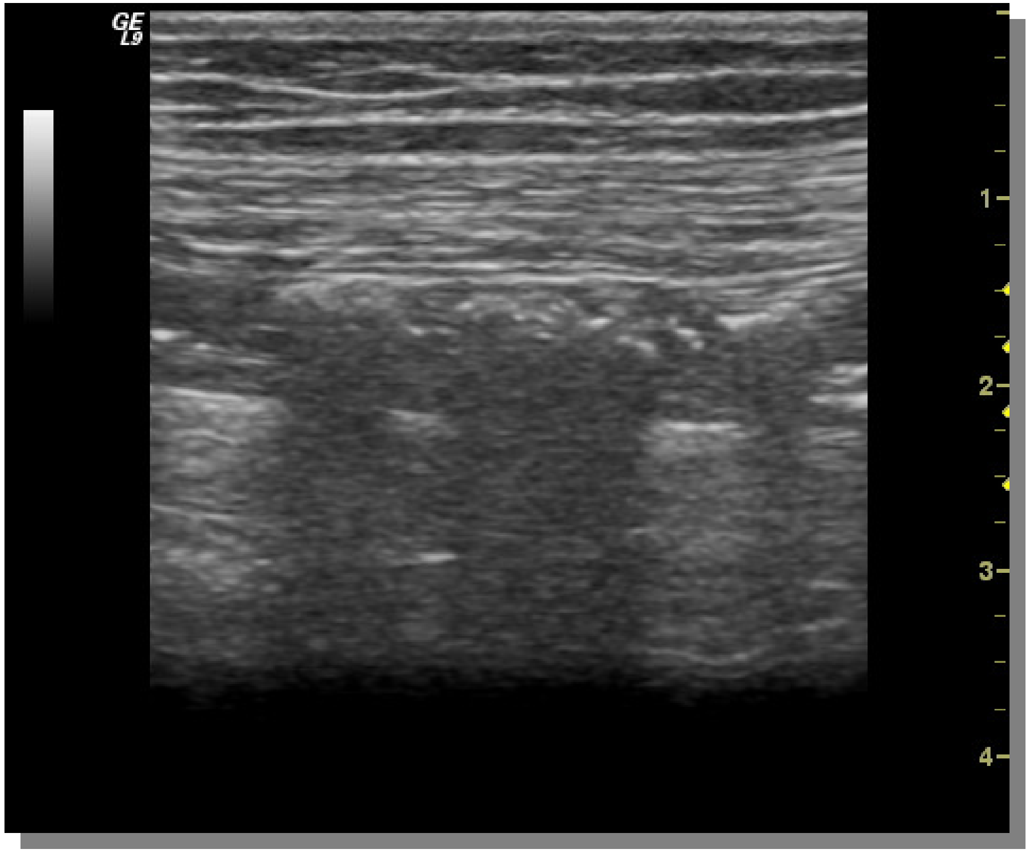


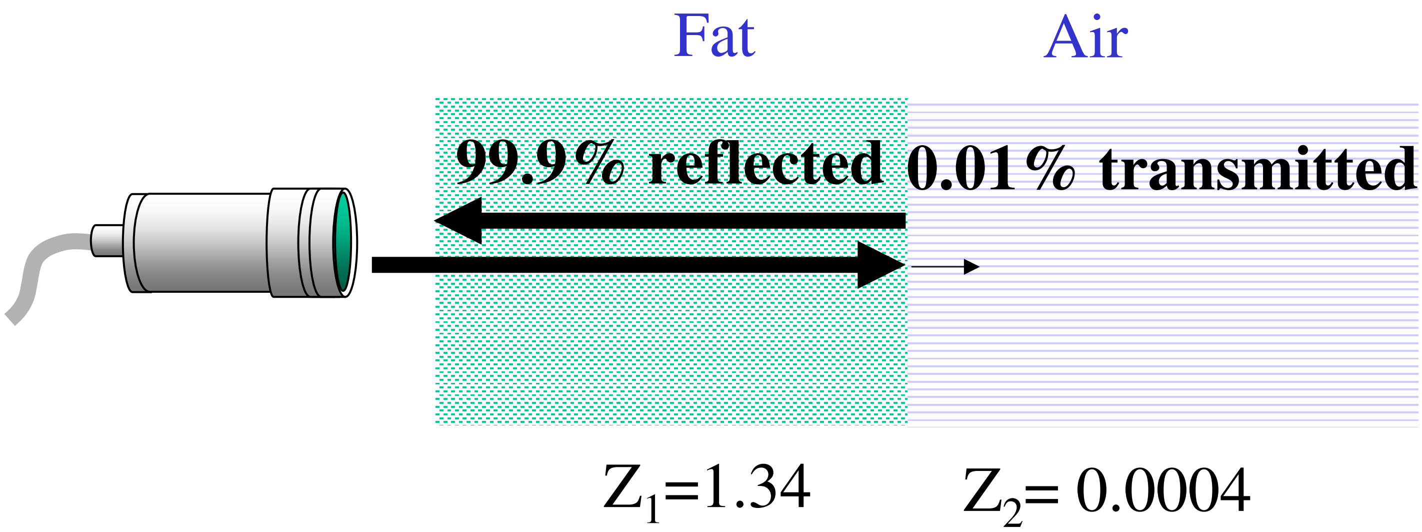
$$R = \frac{P_r}{P_i} = \frac{1.65 - 1.34}{1.65 + 1.34} = 0.10$$



$$R = \frac{P_r}{P_i} = \frac{7.8 - 1.71}{7.8 + 1.71} = 0.64$$

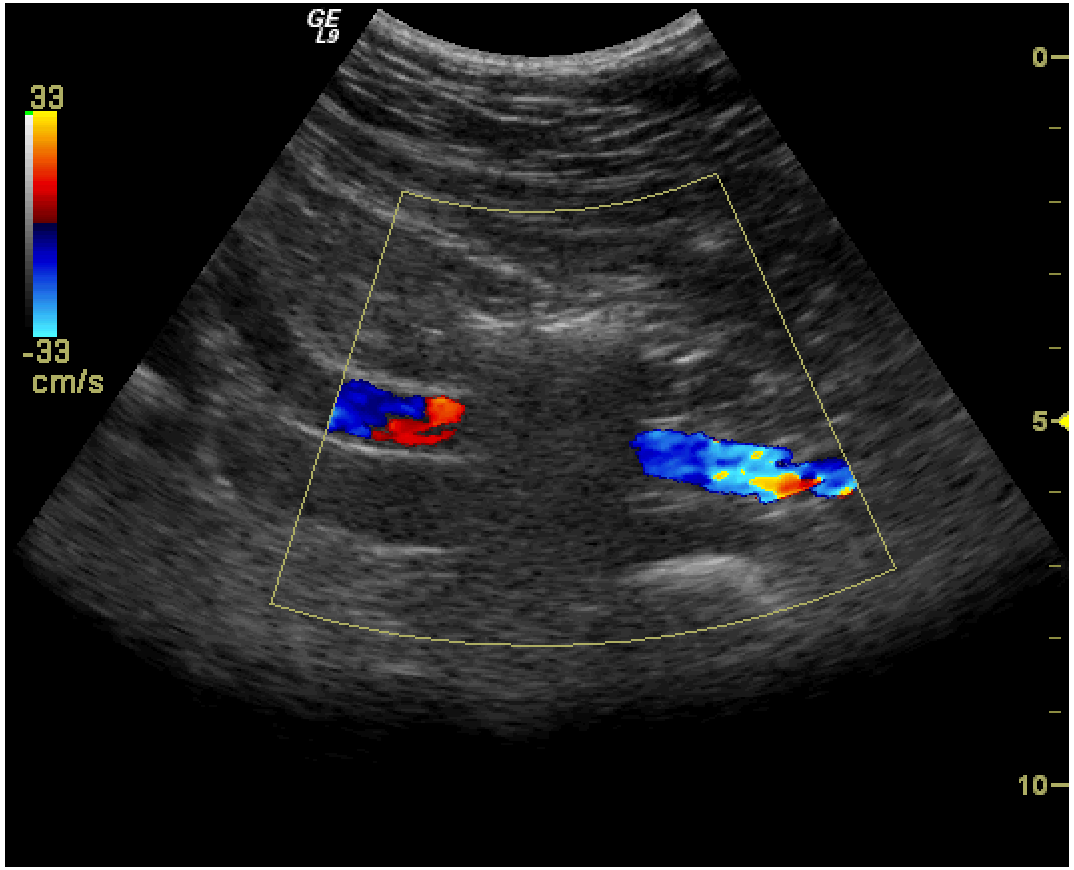
Calcification

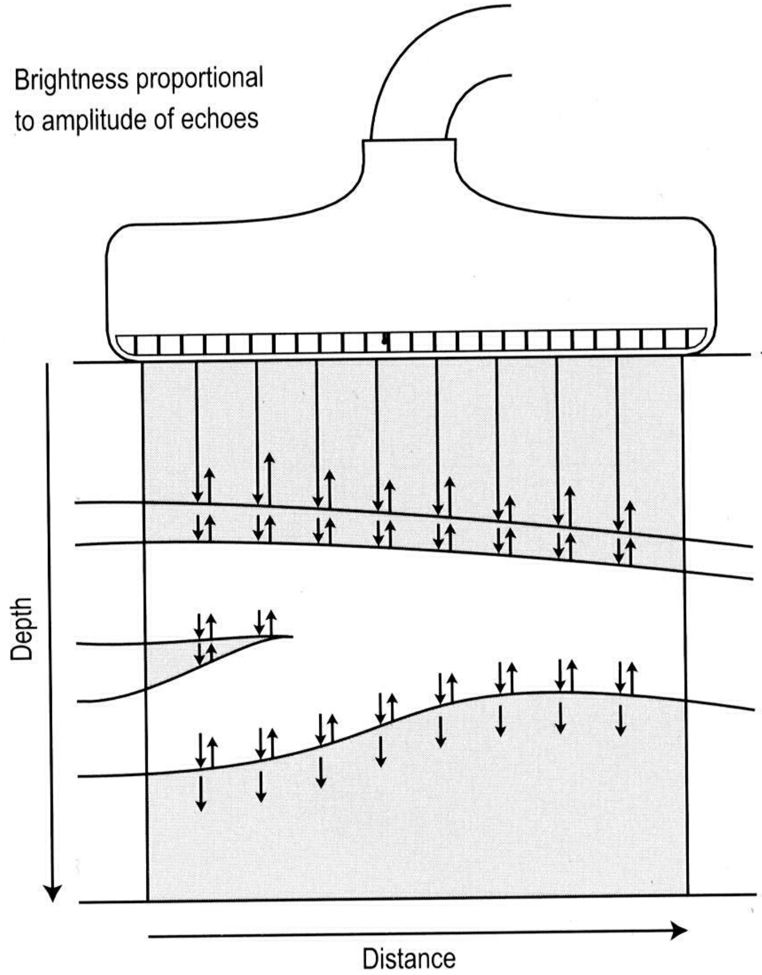


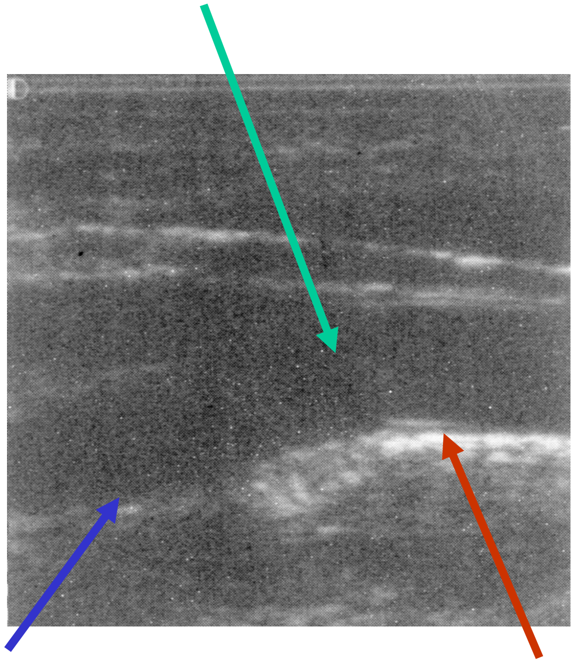


$$R = \frac{P_r}{P_i} = \frac{0.0004 - 1.34}{0.0004 + 1.34} = -0.999$$

Bowel Gas




Brightness proportional
to amplitude of echoes
Depth
Distance


Very weak
Reflection
Weak
Reflection
Strong
Reflection

Reflection

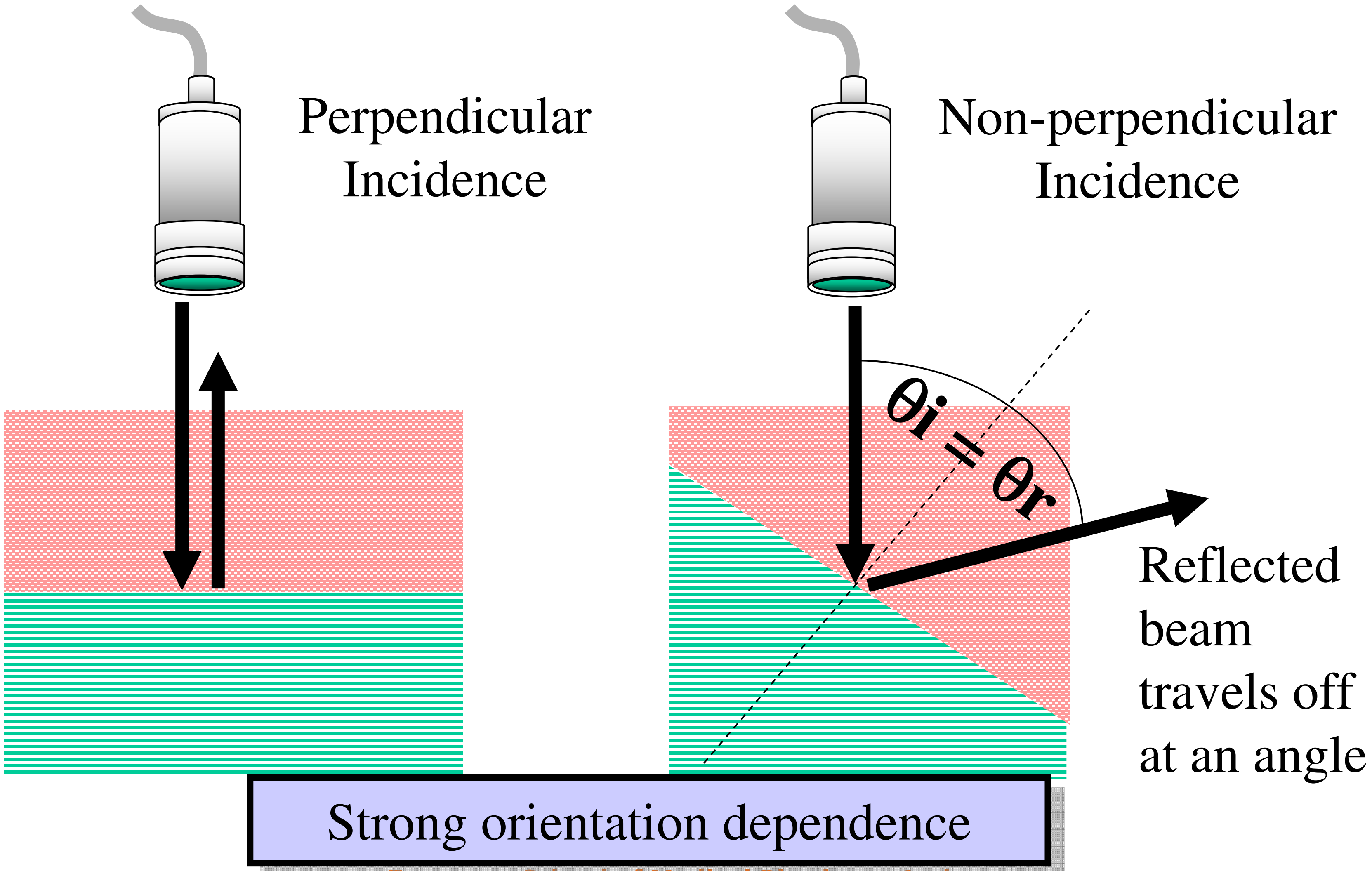
- Specular reflection
  - from large flat boundaries
- Diffuse reflection
  - from small structures
- Rayleigh Scattering
  - from very small structures

Strong

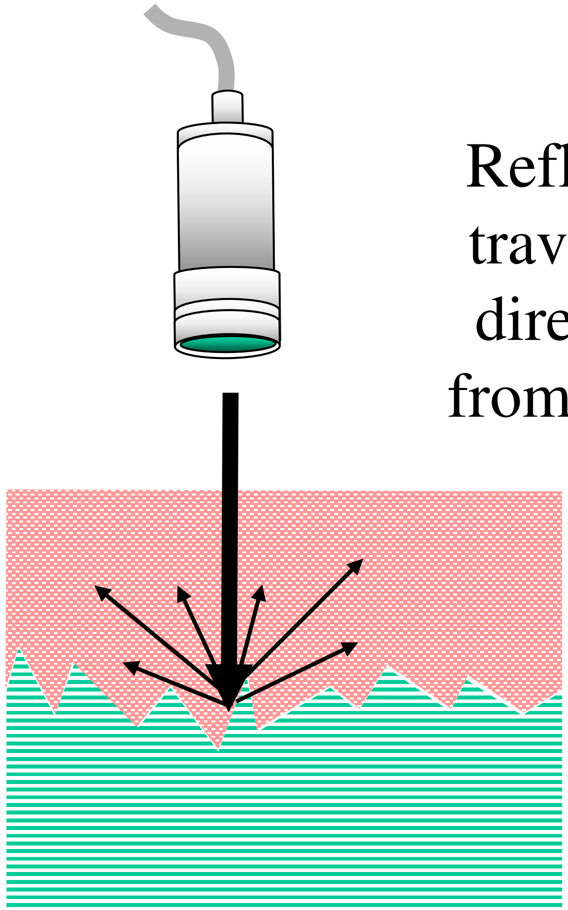
Weak

Very weak

Specular Reflection

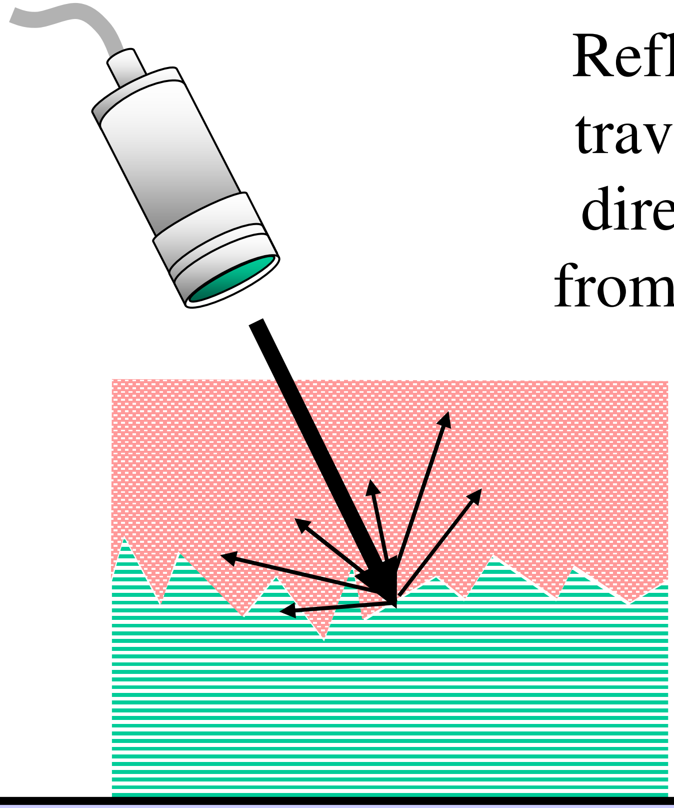


Diffuse Reflection



Reflected waves travel in various directions away from the interface

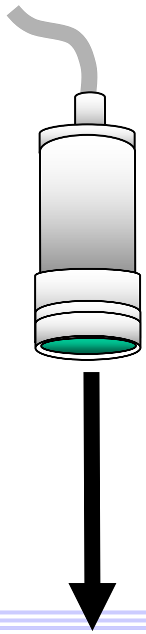
Diffuse Reflection



Reflected waves travel in various directions away from the interface

Some orientation dependence

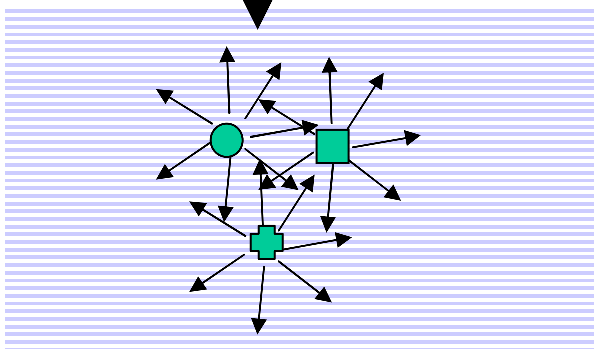
Rayleigh Scattering



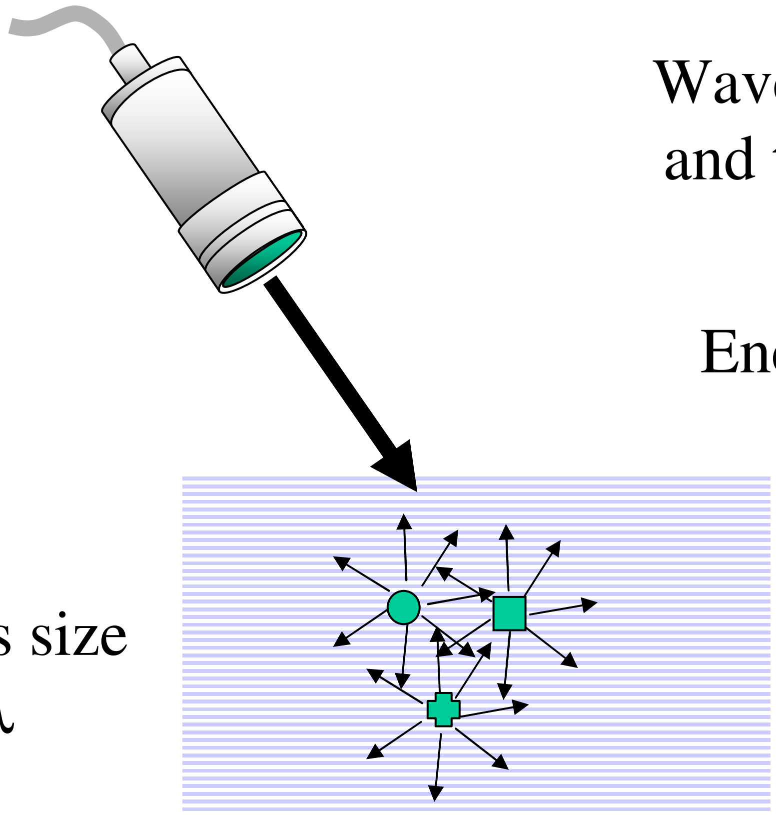
Waves are scattered and travel off in all directions

Energy loss α f^4

Particles size $<<\lambda$



Rayleigh Scattering



Waves are scattered and travel off in all directions

Energy loss α f^4

Particles size $<<\lambda$

Little orientation dependence

Echo Amplitude - Beware!

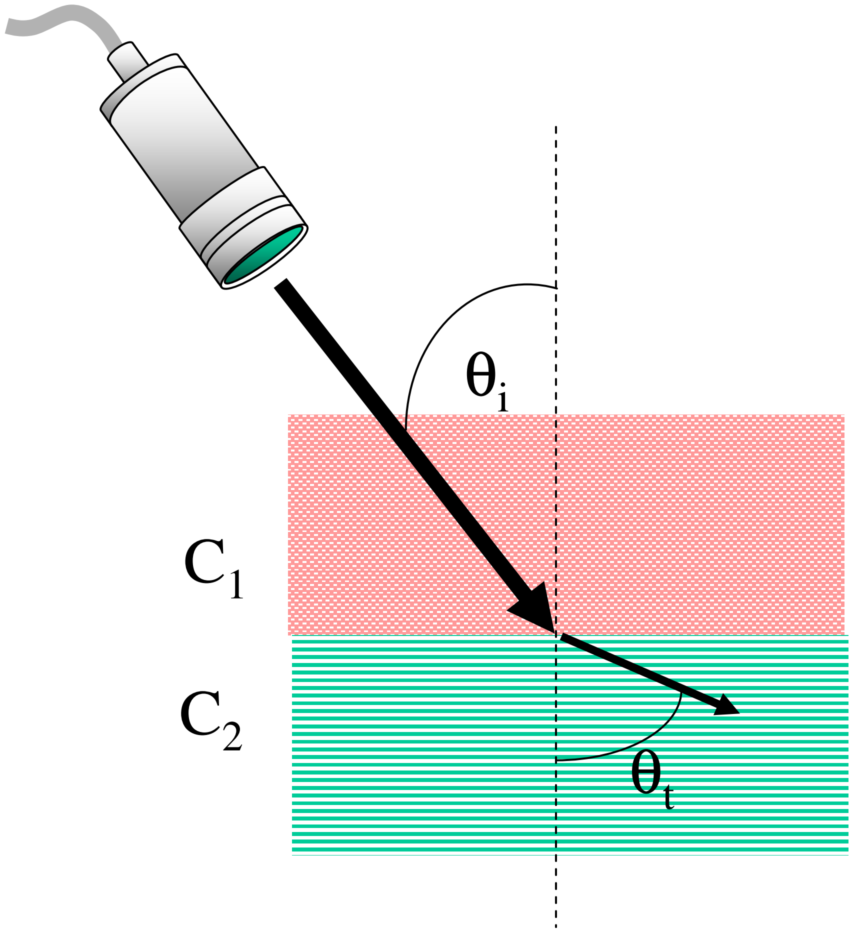
The amplitude of the echoes (image grey level) does ***not*** have a simple relationship with the tissue (unlike X-ray CT [Hounsfield numbers]).

- Echo size depends on
  - relative acoustic impedances across boundary
  - shape and orientation of boundary
  - size of structure compared with λ


Speed of Sound
Impedance
Reflection
Refraction
Attenuation
Non-linear effects
Safety

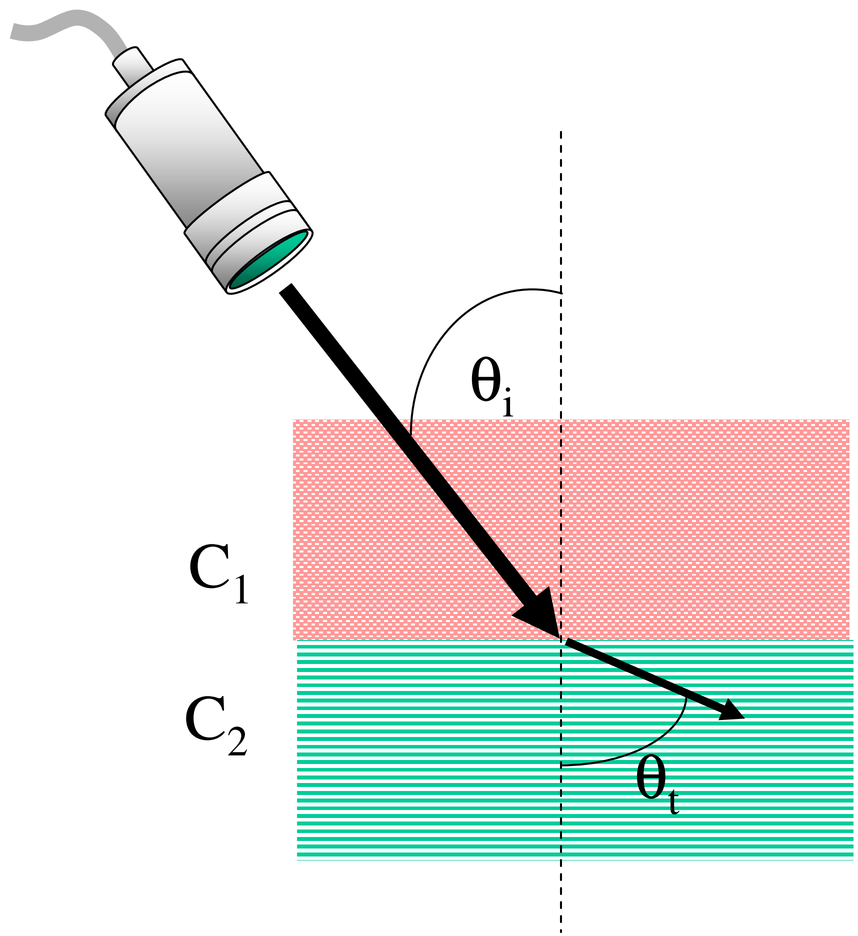
Refraction

- At boundaries between tissues with <u>different velocities</u> i.e. $c_1 \neq c_2$
- The beam direction is changed (if it is not incident normally to the boundary) i.e. $\theta_i \neq \theta_t$
- Beam distortion leads to misregistration
- A problem with fat and muscle



Snell's Law

$$\frac{\sin\theta_i}{\sin\theta_t} = \frac{c_1}{c_2}$$



Refraction - Snell's Law

E.g. Muscle to fat with an angle of incidence of 60°

$$\frac{\sin 60}{\sin \theta_t} = \frac{1600}{1460}$$

$$\theta_t = 52^o$$

i.e 8 degrees difference

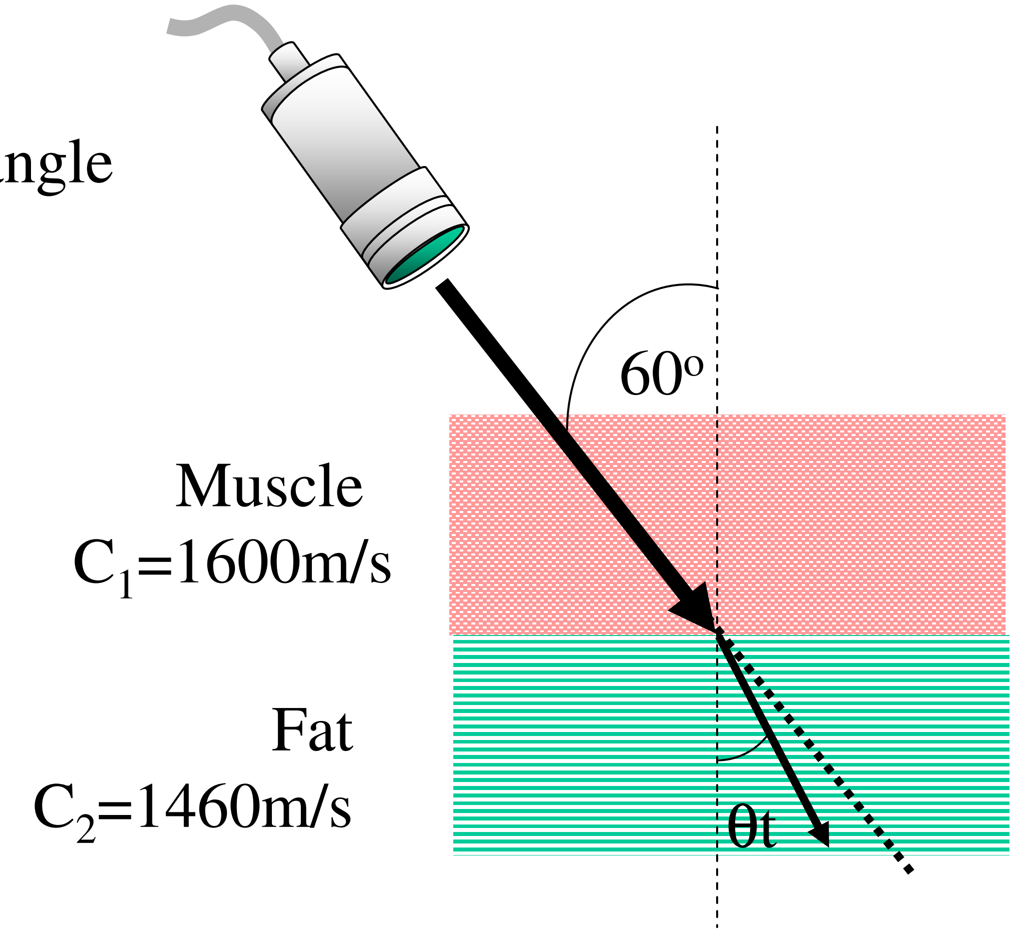
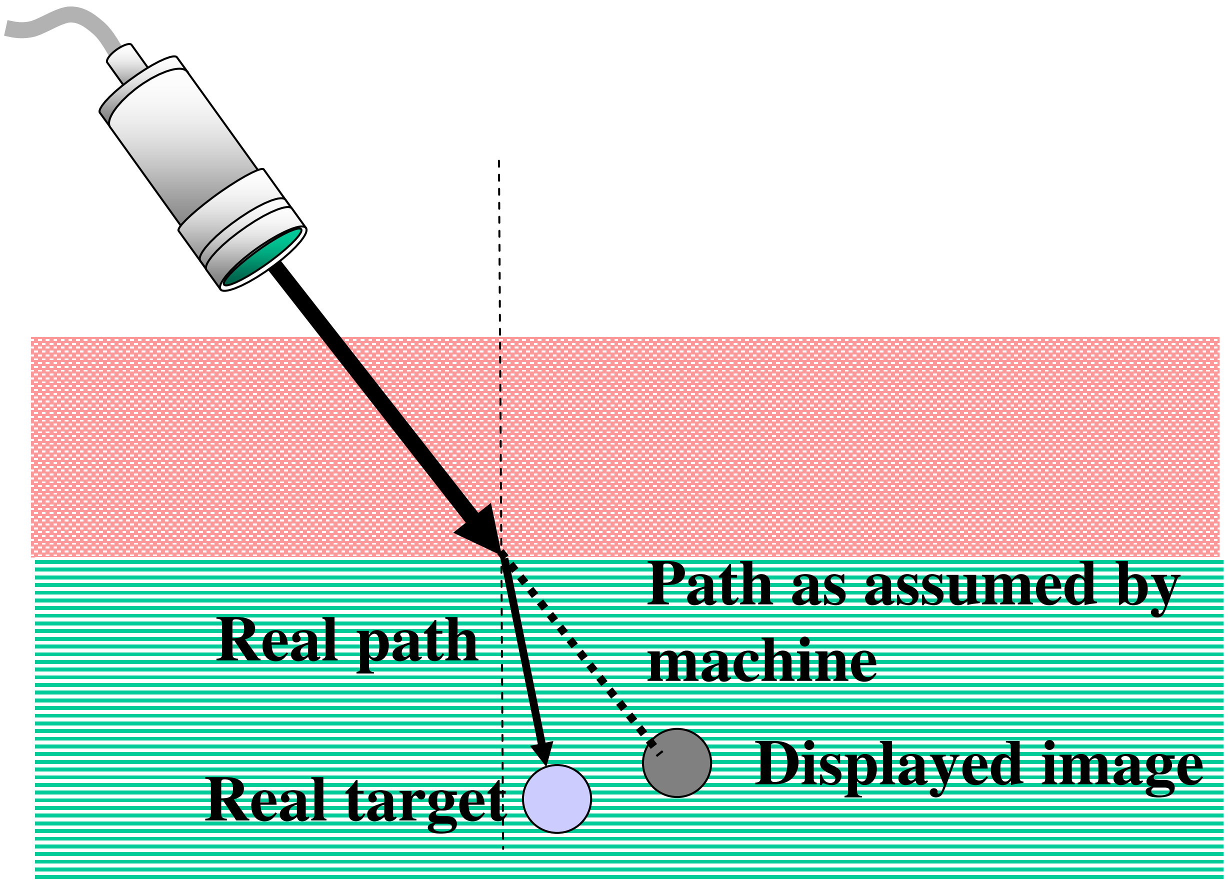


Image Degradation



~~Speed of Sound~~
~~Impedance~~
~~Reflection~~
~~Refraction~~
Attenuation
Non-linear effects
Safety

Attenuation

The energy of the ultrasound beam is reduced with distance

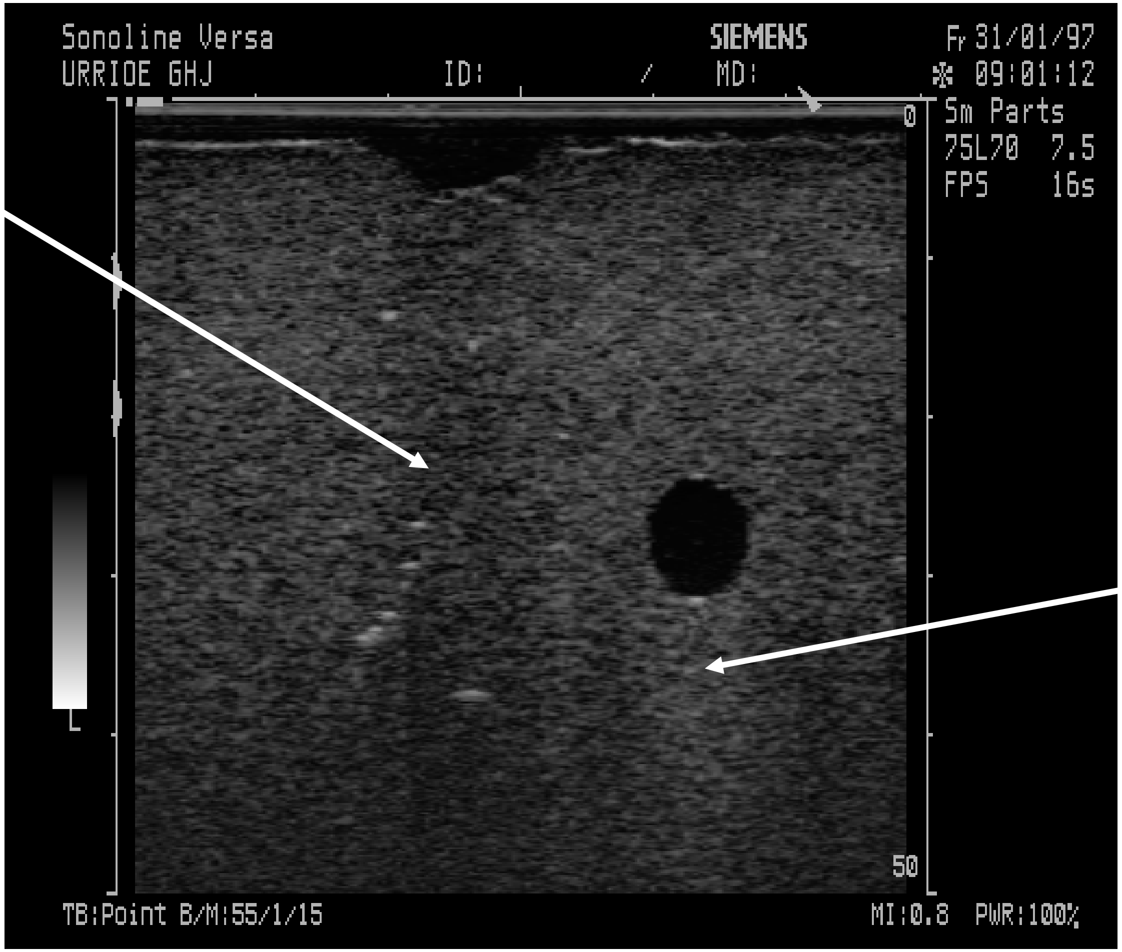
Energy is lost from the beam by:

Scattering (reflection out of beam confines, refraction, divergence)

Absorption (conversion into heat)

Attenuation in an image

Dark deep to the defect in the phantom!

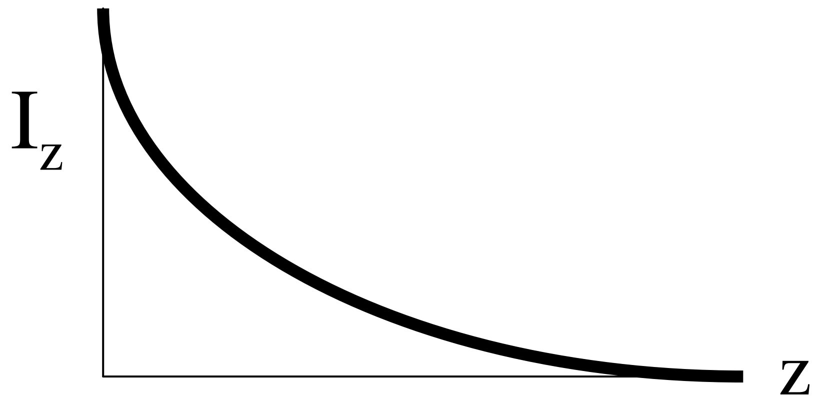


Bright deep to the cyst

Attenuation Coefficient

The intensity, I_z, of an ultrasound beam is related to distance from the source, z, thus:

$$I_z = I_0 e^{-\alpha z}$$



Where I_0 is the intensity at z = 0, the transducer face.

Attenuation Coefficient

Attenuation is approximately exponential,

the slope of the logarithmic graph is constant.

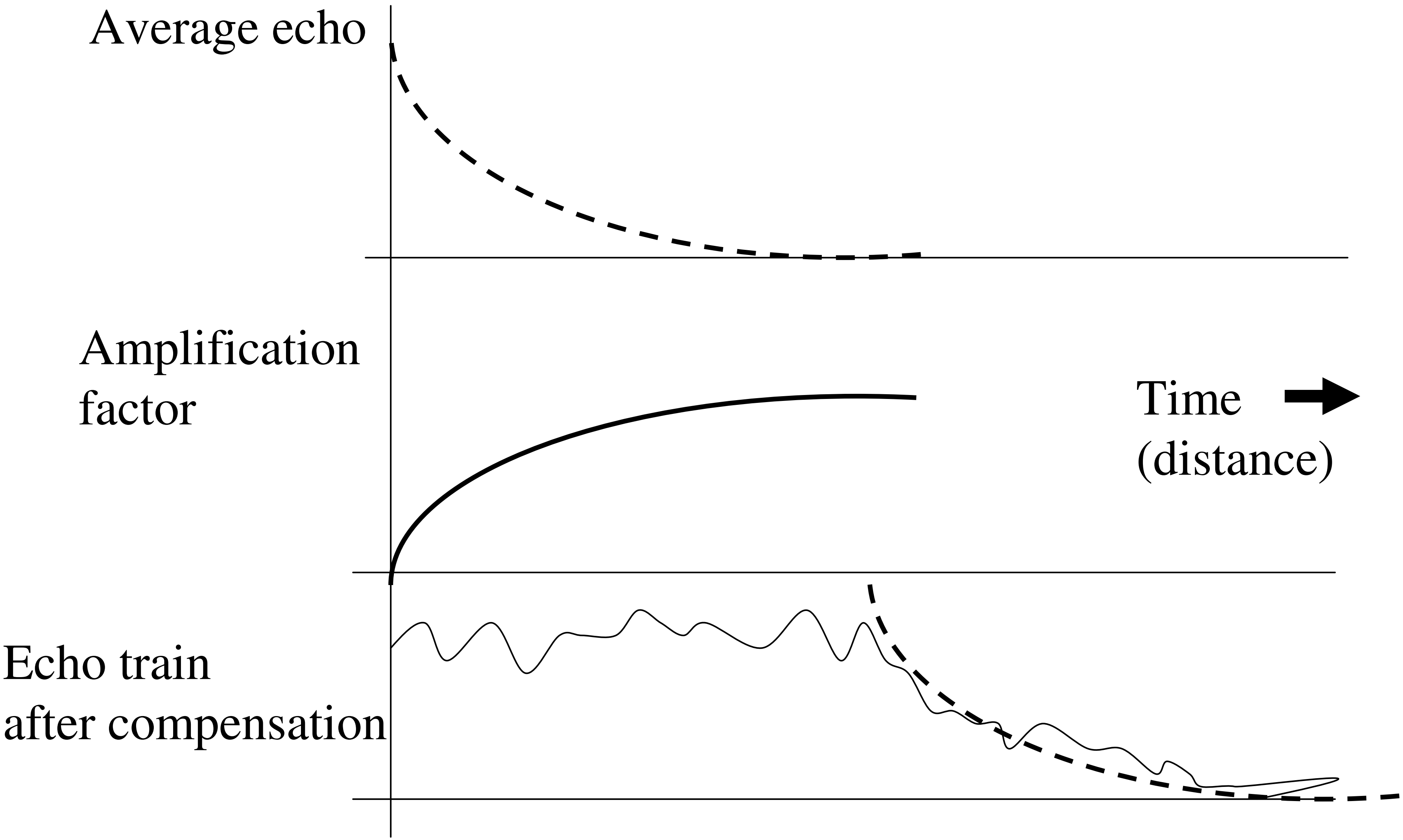
Attenuation coefficient is quoted in dB/cm

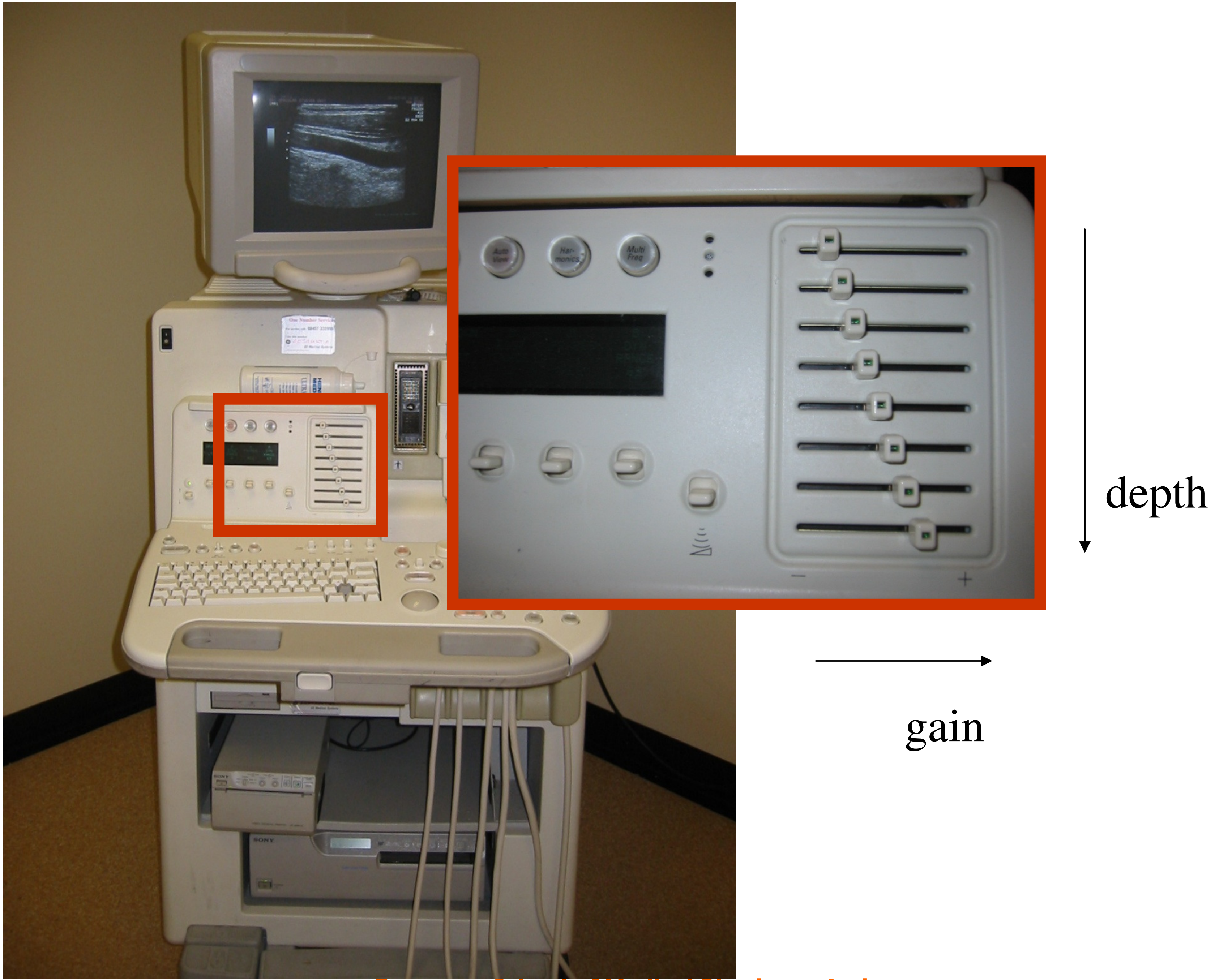
In addition, for soft tissue,

attenuation is proportional to frequency.

The attenuation coefficient for soft tissue is 0.5 - 0.7 dB/cm/MHz

Attenuation - compensation




depth
gain


Speed of Sound
Impedance
Reflection
Refraction
Attenuation
Non-linear effects
Safety

Non-Linear Propagation

Under conditions of relatively high pressure amplitude

the speed of sound is NOT CONSTANT

but varies over the propagation path (z)

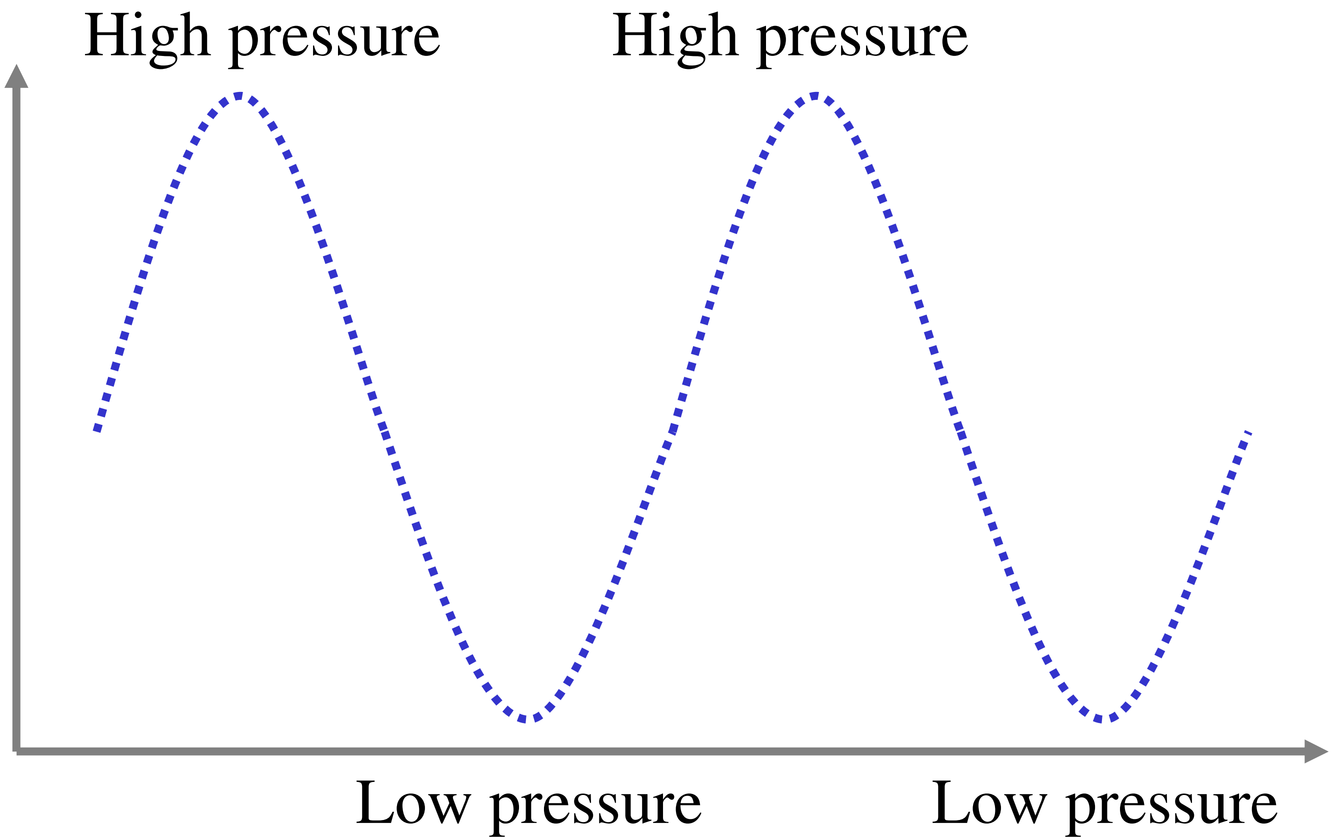
$$c(z) = c_0 + \left(1 + \frac{B}{2A}\right) v(z)$$

$$v = \frac{p}{\rho c}$$

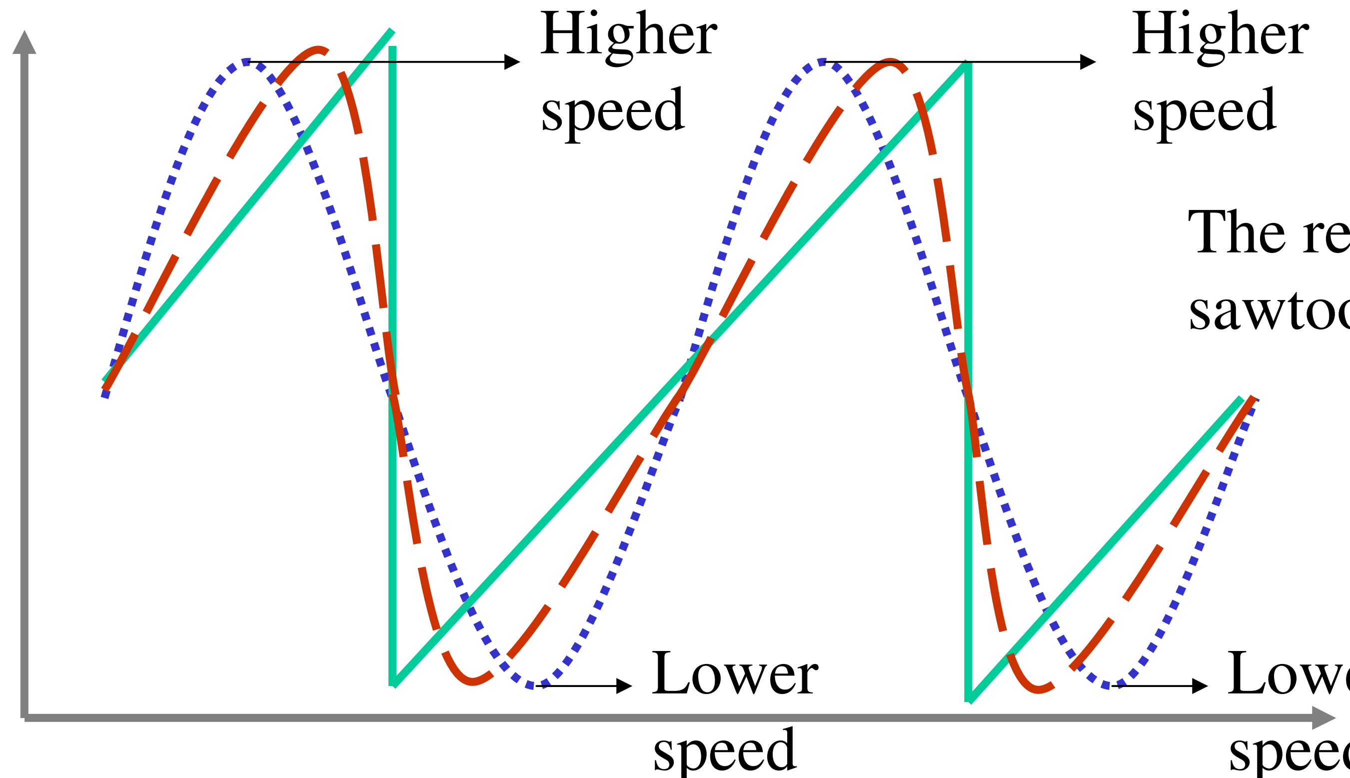
Non-Linear Propagation

$$c(z) = c_0 + \left(1 + \frac{B}{2A}\right) v(z)$$

Material	B/A
water (30℃)	5.2
blood	6.3
liver	7.6
spleen	7.8
fat	11.1

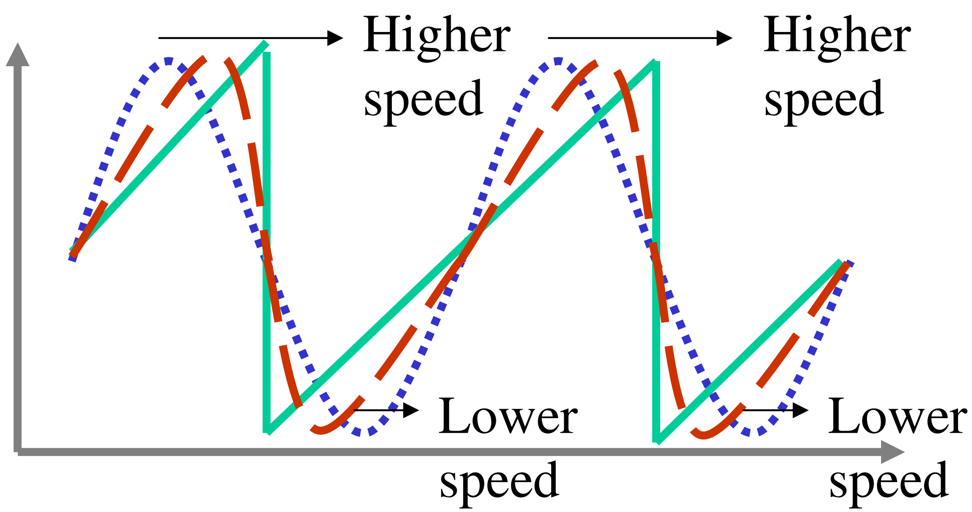

High pressure
High pressure
Low pressure
Low pressure

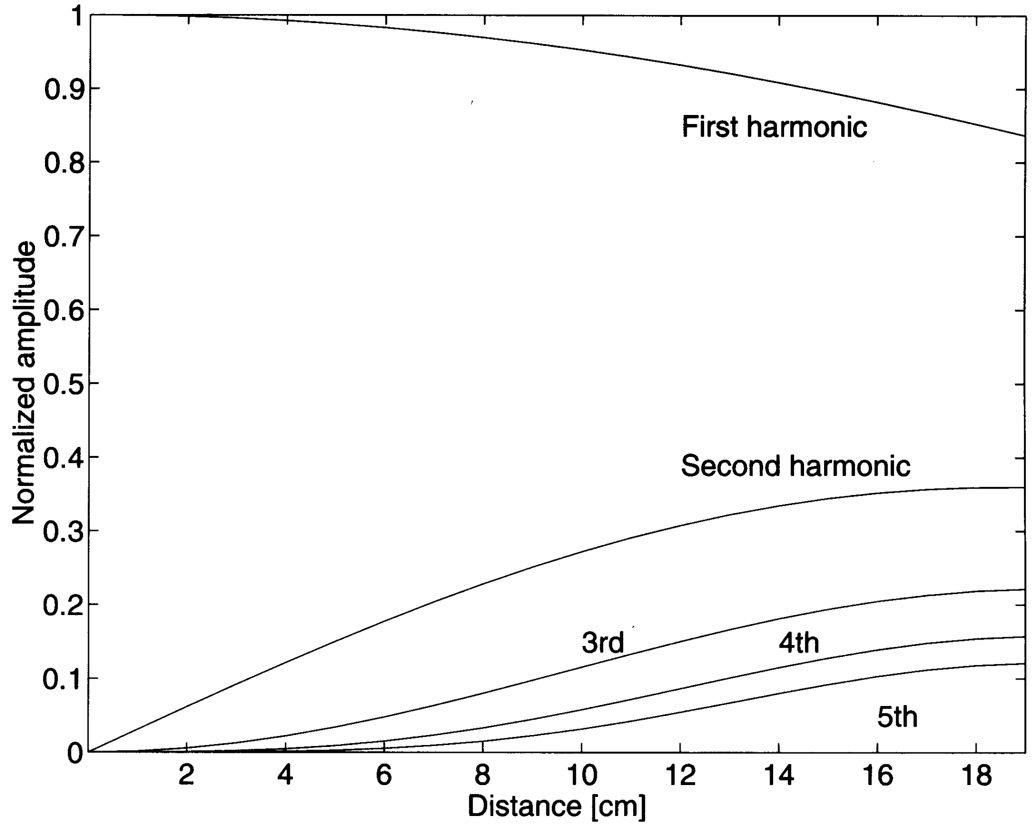
After a sufficient distance, the faster moving high-pressure parts of the wave catch up to the slower low-pressure parts.



The result is a sawtooth wave

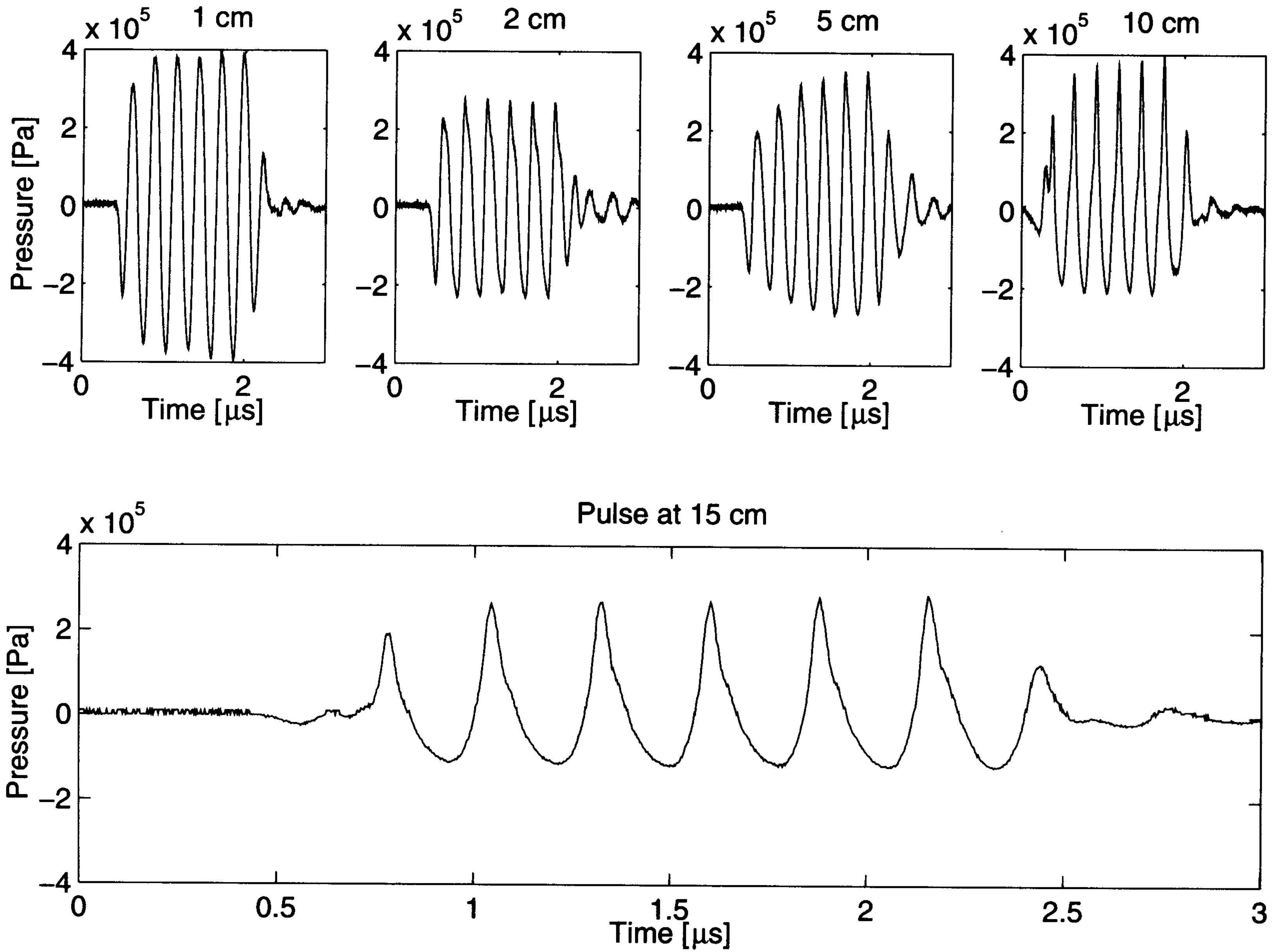
The distorted wave has many **harmonic** frequencies



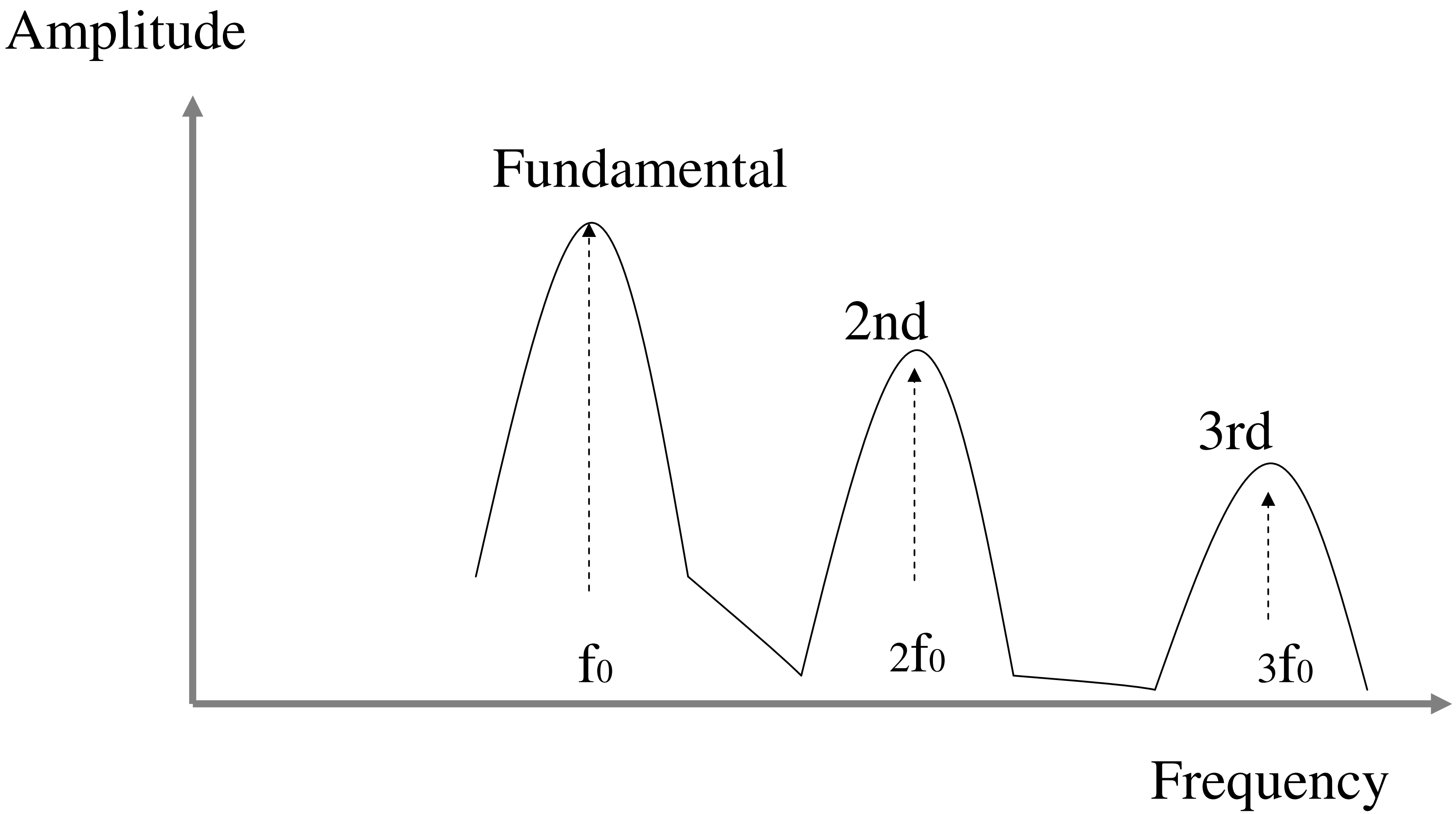


European Scl

Propagation non linéaire



Harmonics



Harmonic Imaging

A relatively recent innovation in diagnostic ultrasound imaging is

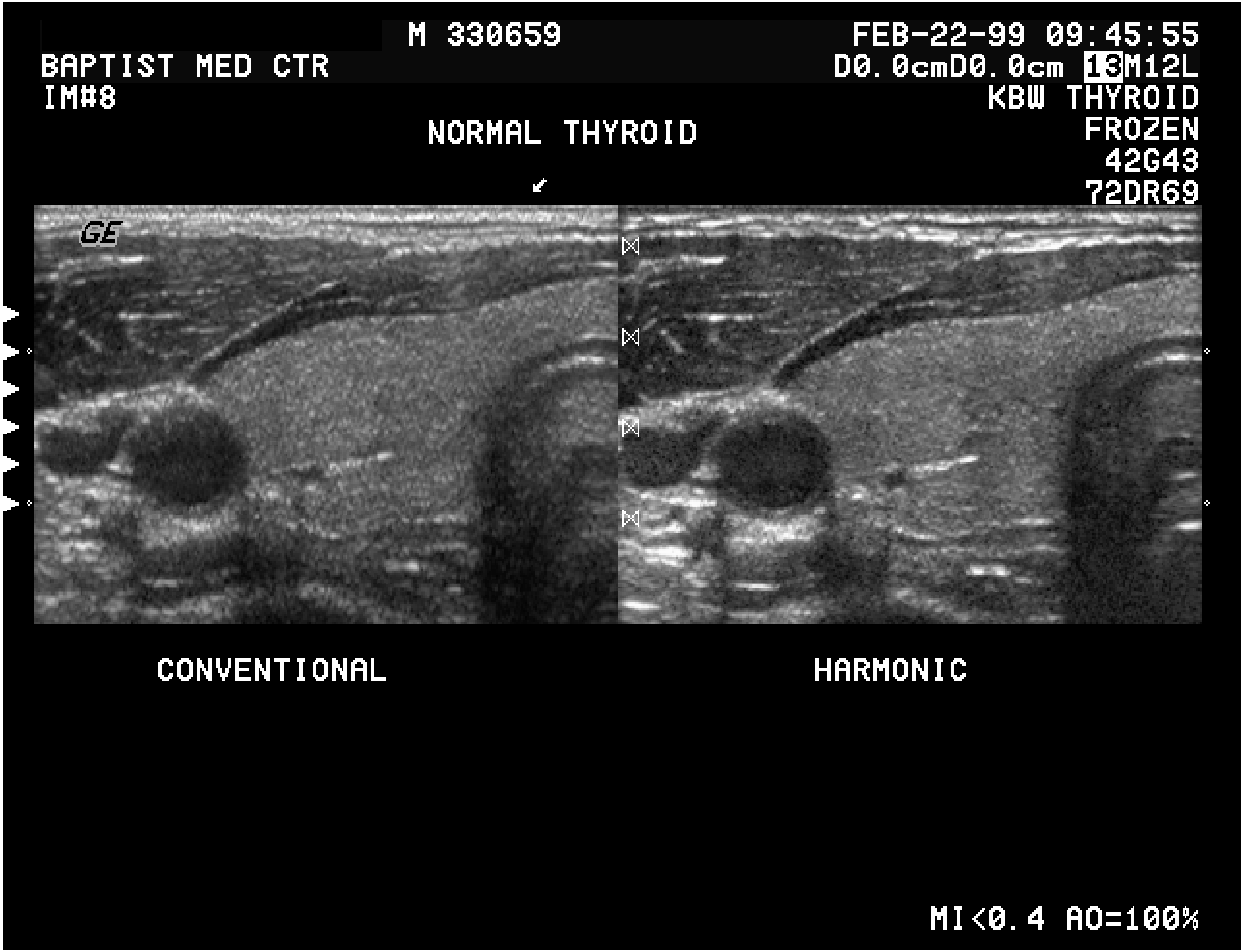
Tissue Harmonic Imaging

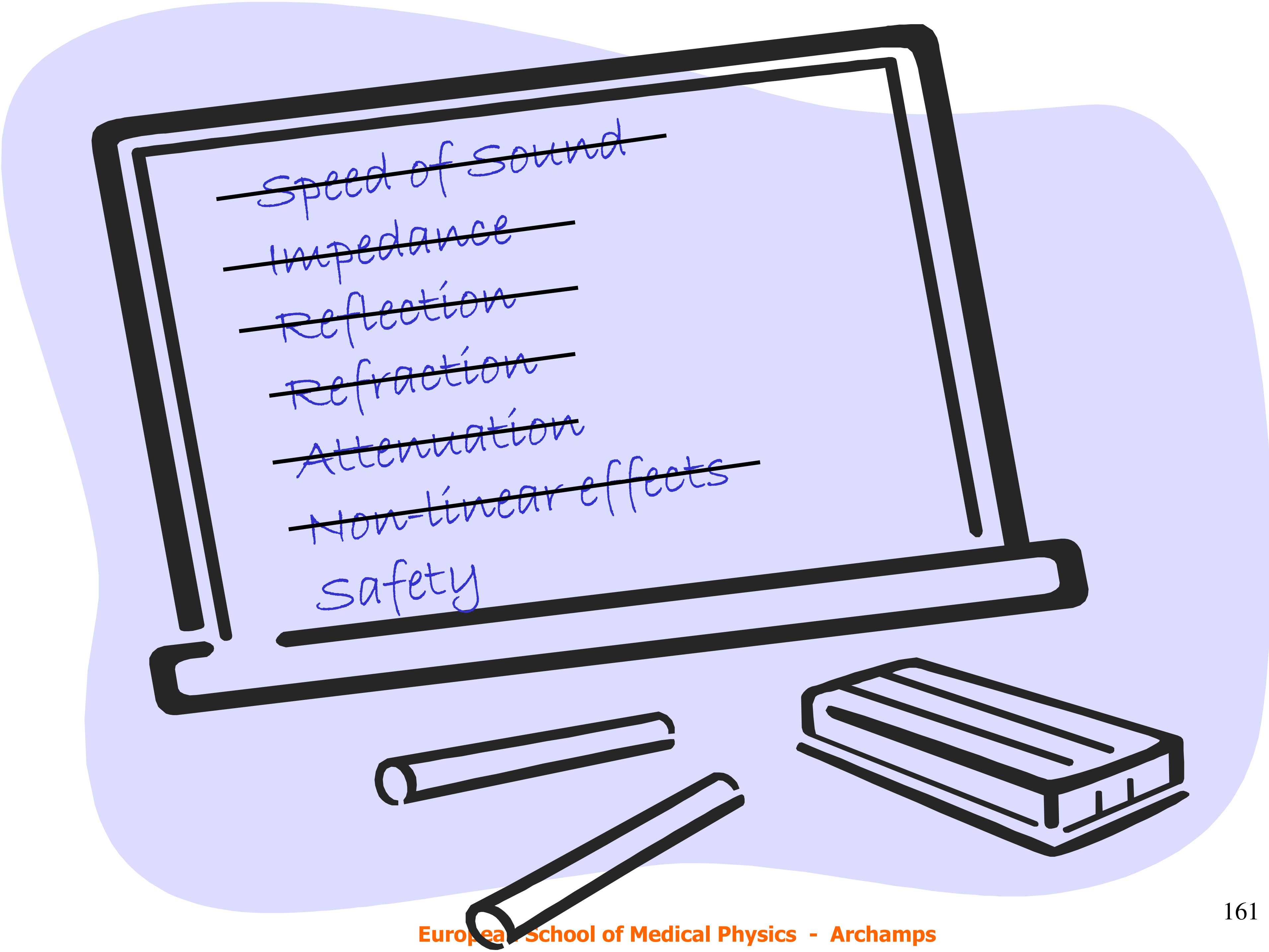
Discovered by accident it uses the effects of non-linear propagation.

"Contrast agents in US"

Ayache Bouakaz

- Native harmonic frequencies are used to improve images
- How?
  - By tuning the receiver to the harmonic frequency ($2F_o$) rather than the transmitted frequency F_o
- Benefits
  - Reduces clutter (noise), increases resolution at depth, improves sensitivity


M 330659
FEB-22-99 09:45:55
BAPTIST MED CTR
D0.0cmD0.0cm 13M12L
IM#8
KBW THYROID
NORMAL THYROID
FROZEN
42G43
72DR69
GE
CONVENTIONAL
HARMONIC
MI<0.4 AO=100%


~~Speed of Sound~~
~~Impedance~~
~~Reflection~~
~~Refraction~~
~~Attenuation~~
~~Non-linear effects~~
Safety

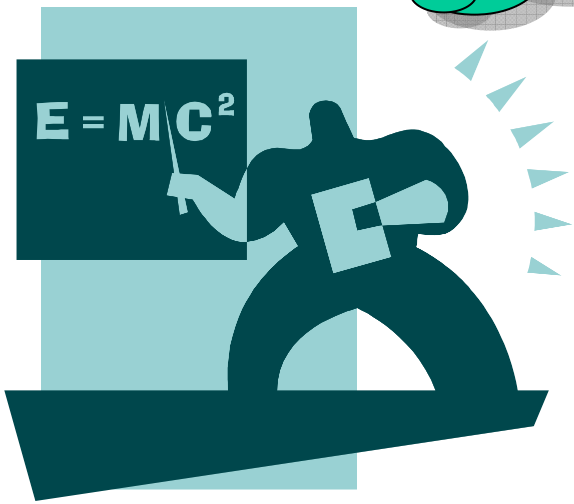
Safety

Possible damage from ultrasound:

- Thermal
  - tissue heating, cell death for T > 42^{o}C
- Mechanical
  - cavitation bubbles for pressures > threshold
    - unfortunately threshold is frequency dependent

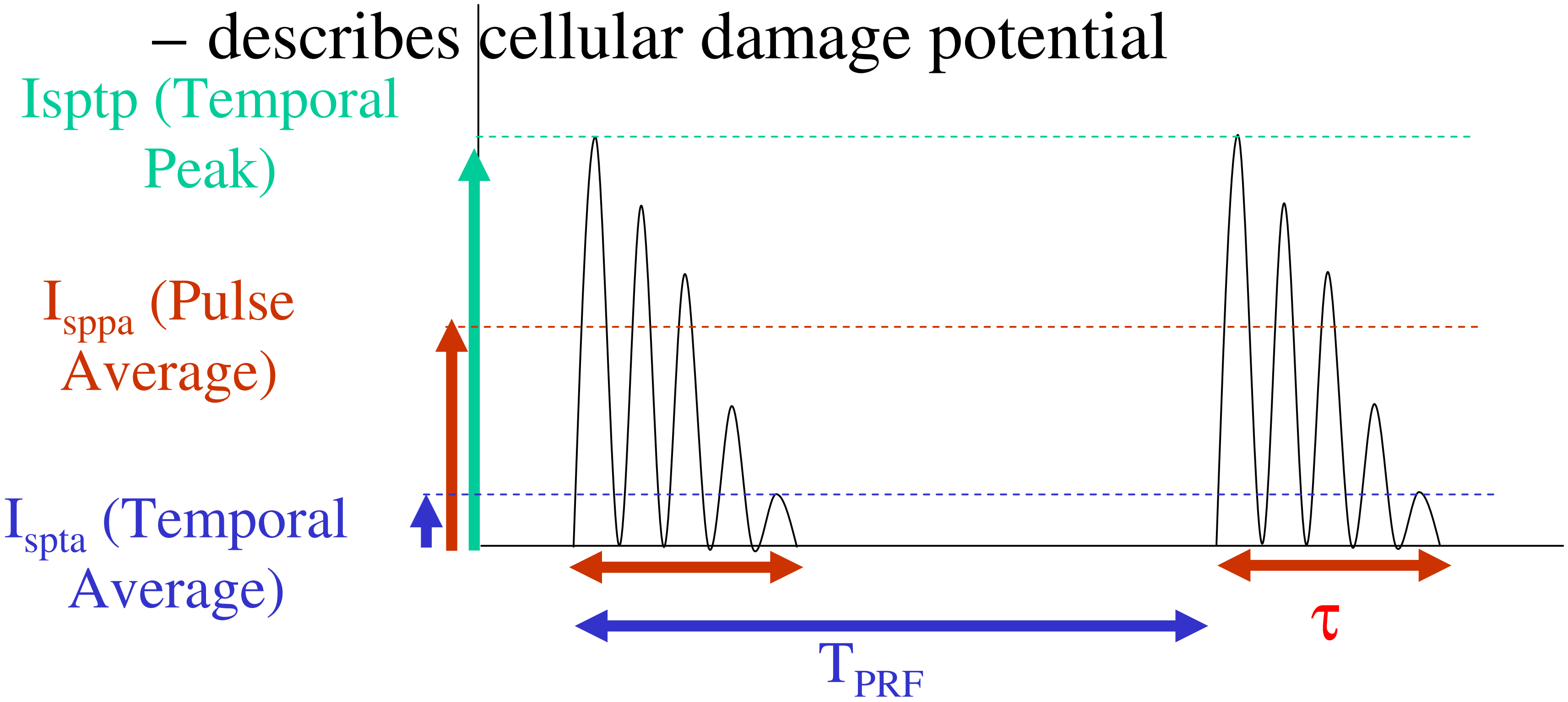
"Therapeutic US principles"

Remy Souchon



Important Intensities

- I_{SPTA} (spatial peak temporal average)
  - describes tissue heating potential
- I_{SPTP} (spatial peak temporal peak)
  - describes cellular damage potential



Example: Acoustical Outputs

Mode	Pr(Mpa)	I_{SPTA}(mW/cm^2)	I_{SPPA} (W/cm^2)	Power(mW)
B	1.68	18.7	174	18
M	1.68	73	174	3.9
PD	2.48	1140	288	30.7
CF	2.59	234	325	80.5

Mechanical and Thermal Indices

- Thermal index
  - relates to temperature
  - potential for heating effects (metabolic rate)

- Mechanical Index
  - relates to pressure
  - potential for bubble effects (cavitation)

Thermal Index

- TI is the ratio between:
  - the power exposing the tissue, W
  - the power required to cause a 1^{o}C temperature rise, W_{deg}

$$TI = \frac{W}{W_{deg}}$$

Mechanical Index

- MI describes the likelihood of the negative pressure causing bubble activity

$$MI = \frac{P_{-d}}{\sqrt{f}} \qquad \frac{\text{megapascals}}{(\text{megahertz})^{1/2}}$$

P_{-d} is the 'derated' pressure at the site in the body

f is the frequency of the pulse

MI and TI in practice

	important	not so important
MI	contrast agents lung (cardiac) bowel gas (abdominal)	absence of gas bodies (most soft tissue studies)
TI	1st trimester fetal skull and spine ophthalmic fever poor perfusion	good perfusion (liver, spleen) cardiac vascular

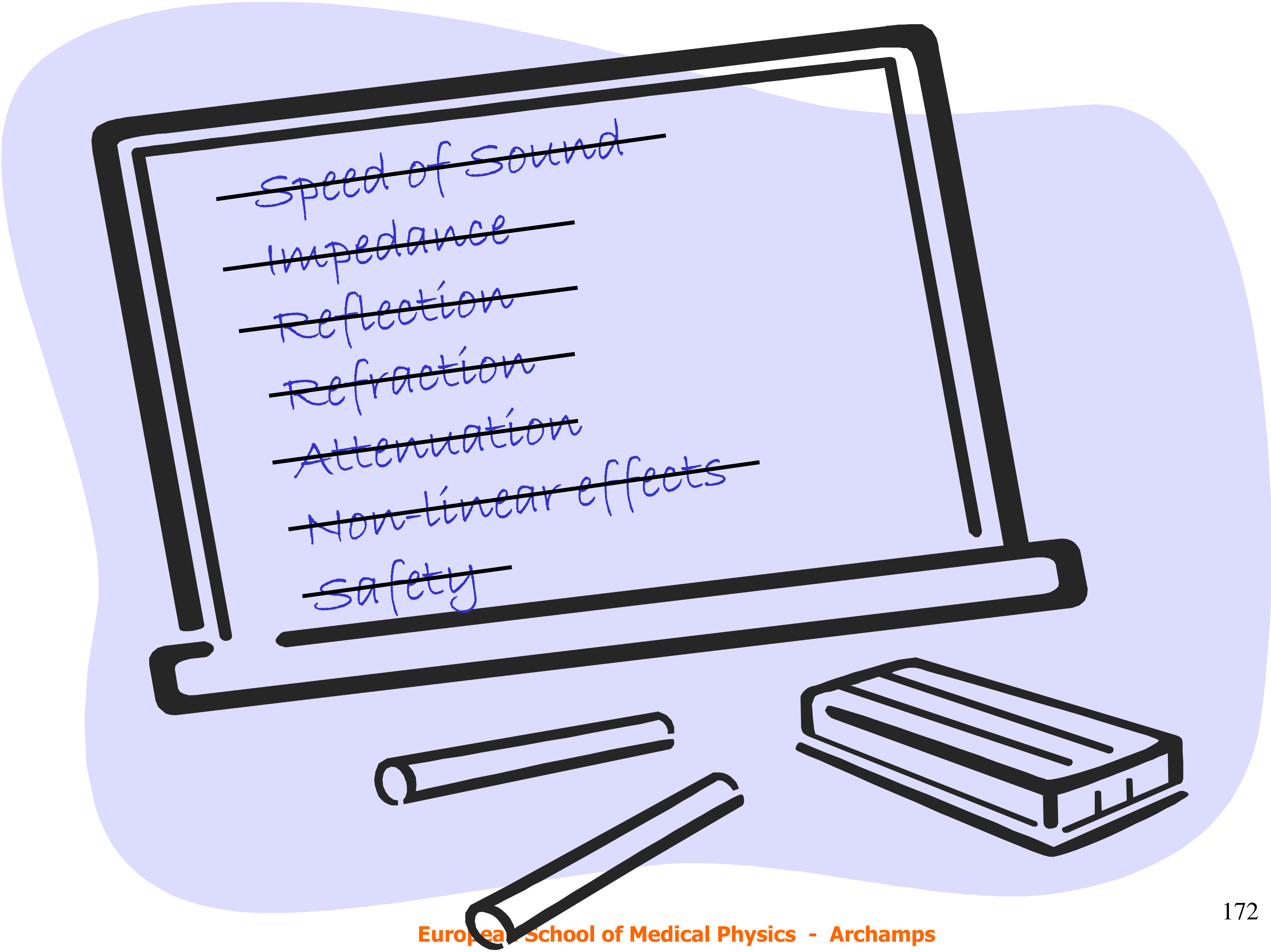
Guidelines

- MI>3 Possibility of minor damage to neonatal lung or intestine
- MI>0.7 Theoretical risk of cavitation.

- TI>0.7 Restrict exposure time of a fetus
- TI>1.0 Eye scanning not recommended
- TI>3.0 Fetal scanning not recommeded

“Q-assurance of US equipment”

Chris de Korte


Speed of Sound
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Scanner settings

•Fixed settings : MI, TCG, gain

•Adjustement: focus, sector size

PHILIPS

TOSHIBA


Ultrasound
Systems


Ultrasound
Systems


Ultrasound
Systems

SIEMENS


Welcome to the GE Ultrasound product family

References

- Ultrasound Imaging, Bjorn A. J. Angelsen, ISBN 82-995811-0-9, Emantec AS, Trondheim, Norway, www.ultrasoundbook.com
- Ultrasound in Medecine, Institute of Physics, Publishing Bristol and Philadelphia

It's all over….