Basic Physics of Ultrasound

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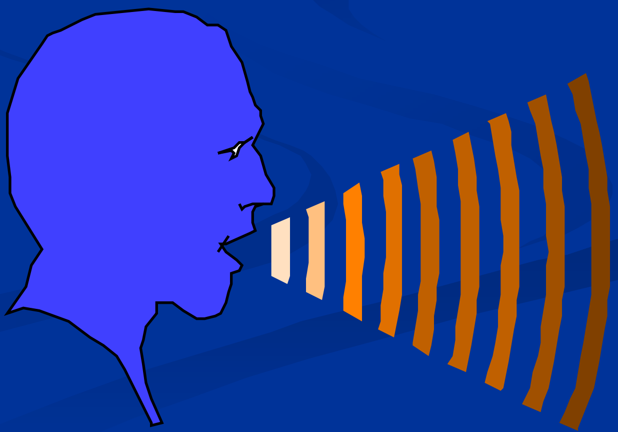
What is Sound?

- A Mechanical Pressure wave (Vibrations) consisting of a series of compressions and expansions through a medium.
- Measured in Hz (cycles/sec.)
- Audible sound 20~20,000 Hz (frequency)
- Travels in the form of a wave

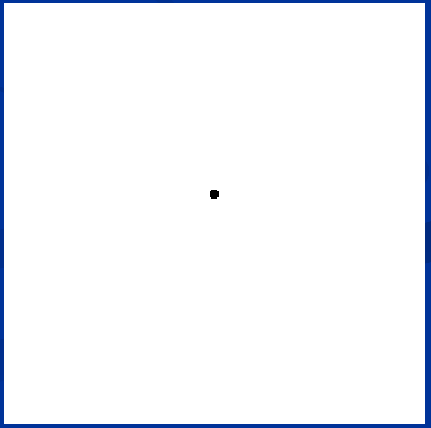


Stationary Sound Wave

- Sound waves are produced at a constant **frequency f** , and the wavefronts propagate symmetrically away from the source at a constant **speed v**, which is the speed of sound in the medium.
- Distance between wave fronts = **wavelength** λ

Speed = frequency x wavelength

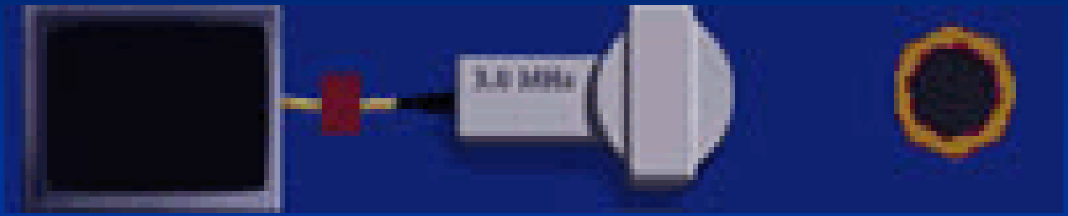
$$V = f \times \lambda$$



What is Ultrasound?

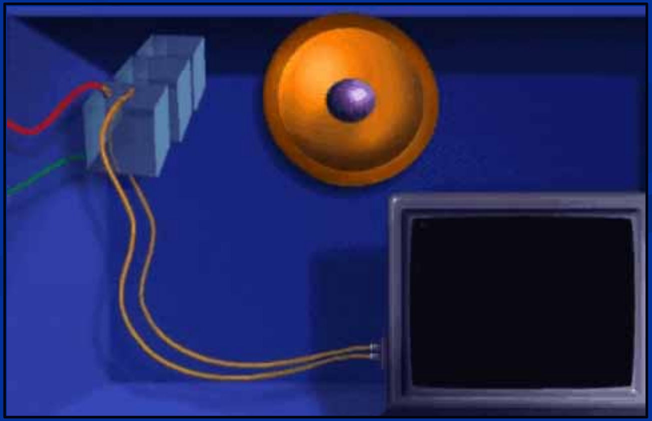
- Sound waves above a frequency of 20,000 Hz
- Infrasound - 0-20 Hz
- Audible sound - 20 Hz to 20,000 Hz
- Ultrasound - >20,000 Hz (or 20 KHz)
- Medical ultrasound - 2.5 MHz to 15 MHz

How is the Image Formed on the Monitor?



- Piezoelectric crystals in transducer of Scan head produces “pulses” of ultrasound
- Transmission through tissue medium
- Reflection from tissue interfaces
- Signal (echos) returns to system → electric signal

- Signal Processing
- → image of all reflections
  formed on the monitor



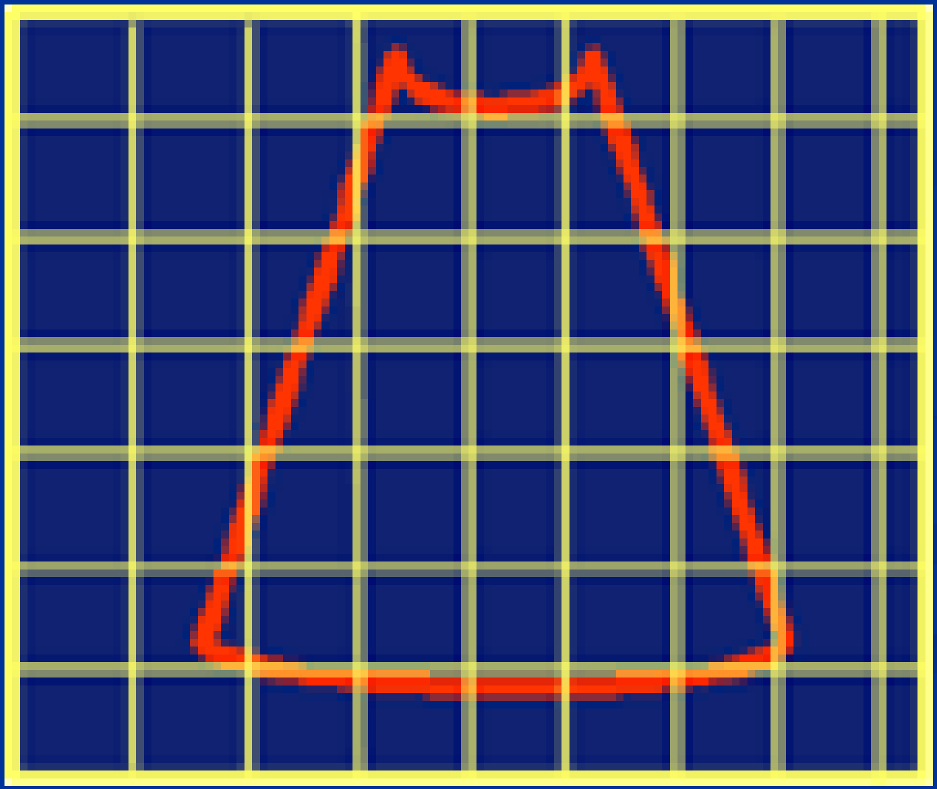
How is the Image Formed on the Monitor?

- Transducers has dual function: Transmits (1%) & Receives (99%)
- The strength or amplitude (brightness) of each reflected wave is represented by a dot
- The position of the dot represents the depth from which the returning echo was received
- These dots are combined to form a complete image

Image Display

Position of Displayed Echo's?

- The display screen is divided into a matrix of PIXELS

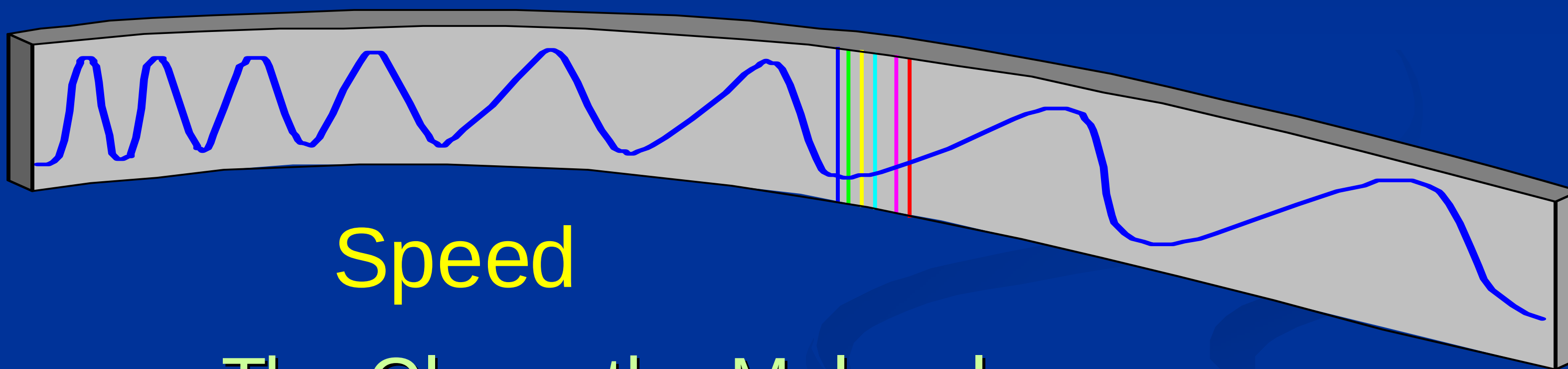


Sound Wave Propagation

Bone
4080m/s

Tissue
1540 m/s

Gas
330m/s



Speed

The Closer the Molecules,

The Better the Propagation

Tissue Propagation velocity (v) In order to calculate distances and place objects at the appropriate depth an average soft tissue velocity of **1540meters/second** (1.54 mm per microsecond) is assumed

Reflection

- The fundamental principle of ultrasound imaging is reflection of ultrasound waves from surfaces in the path of the beam. These reflections are detected by the transducer and generate the image displayed on the screen

- *The degree of reflection is related to changes in acoustic impedance (Z) between two tissue interfaces*

- Homogenous zones with relatively uniform acoustic impedance produce echo free areas.

Reflection of Sound

- Specular reflectors (diaphragm)
  - provide more returned signal
  - best if perpendicular to sound beam
- Scatter reflectors (RBCs)

Interaction among waves

Interference

- Determined by the medium 's density and homogeneity
- Specular reflections obtained when the width of reflecting object is greater than one fourth of the wavelength of ultrasound

  To visualized smaller image → shorter wavelength λ

- By increasing frequency of the ultrasound beam

$$V = f \times \lambda$$

How is the Image formed on the Monitor?

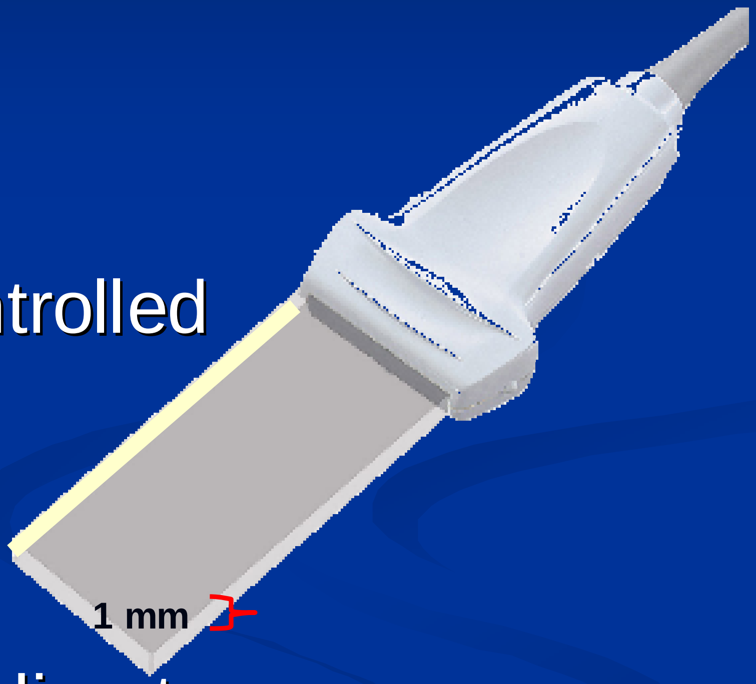
- Strong reflections HYPERDENSE = White dots
  Diaphragm, gallstones, bone

- Weaker reflections = Grey dots
  Most solid organs, thick fluid

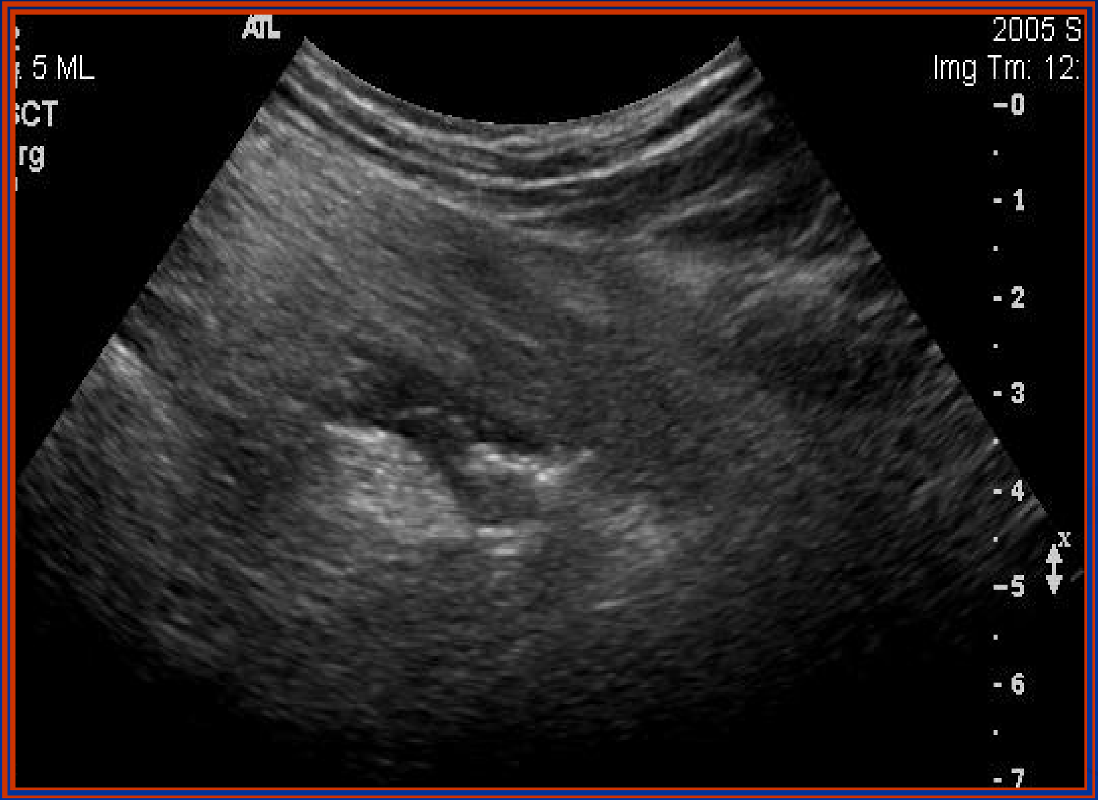
- No reflections (HYPODENSE)= Black dots
  Fluid within a cyst, urine, blood

Ultrasound Beam

- Beam comes out as a slice
- Beam Profile
  - Approx. 1 mm thick
  - Displayed depth user controlled
- Image produced is "*2D*"
  - tomographic slice
  - assumes no thickness
- You control the beam according to your aimed target

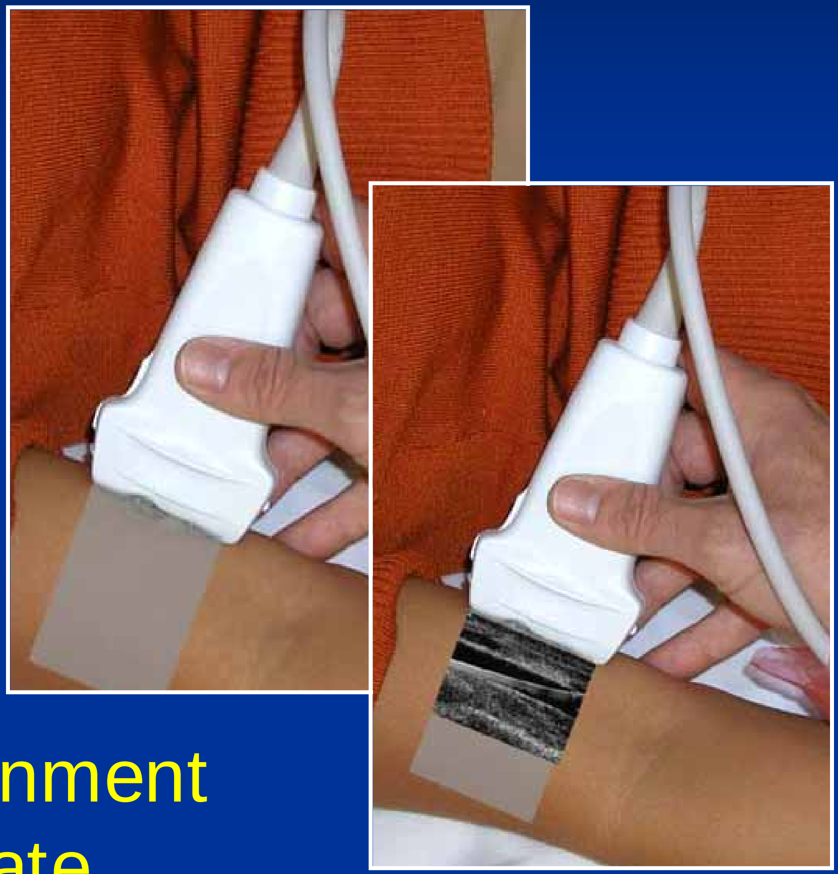


Ultrasound Beam Depth



Perpendicular Approach
Offers Best Reflection
(short axis, cross-sectional)

Ultrasound Beam Control



Alignment
Rotate
Tilting
Scan up and down

Ultrasound Frequency

- **Hertz Hz**, a unit of frequency of equal to one cycle per second

What is MHz? Abbreviation for ***megahertz***

- One MHz represents one million cycles per second.

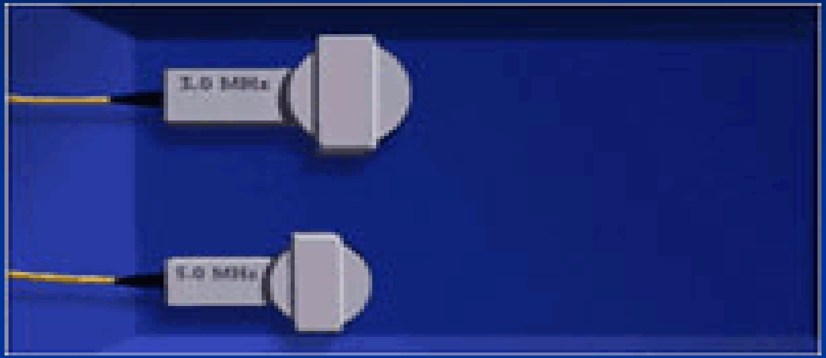
- ◆ Increase Transducer Frequency:
- ◆ Improve Resolution (axial & lateral)
- ◆ Decrease Penetration

- ◆ Higher Frequency Transducers are used to image superficial structures when penetration is not of concern

Transducer Frequency and Resolution

3.0 MHz

5.0 MHz



- ↑ **Frequency = ↑ Resolution** → Axilla, Neck

  A 12 MHz scanhead has very good resolution, but decrease penetration

- **Frequency = ↓ Penetration** → Back , Buttock

  A 3 MHz scanhead can penetrate deep into the body, but the resolution is not as good as the 12 MHz scanhead

Axial Resolution and Frequency

	Axial resolution
5 MHz	0.6 mm
7.5 MHz	0.4 mm
12 MHz	0.25 mm
20 MHz	0.15 mm
30 MHz	0.1 mm

Low-frequency probes (3-5 MHz) Deep abdominal organs such as liver, gallbladder, and kidneys Scanning

High-frequency probes (10-15 MHz) superficial structures such as the brachial plexus requires that provide high axial resolution. However, beam penetration is limited to 3 to 4 cm.

Mid-frequency probe (4-7 MHz) deeper structures, such as the brachial plexus in the infraclavicular region and the sciatic nerve in adults.

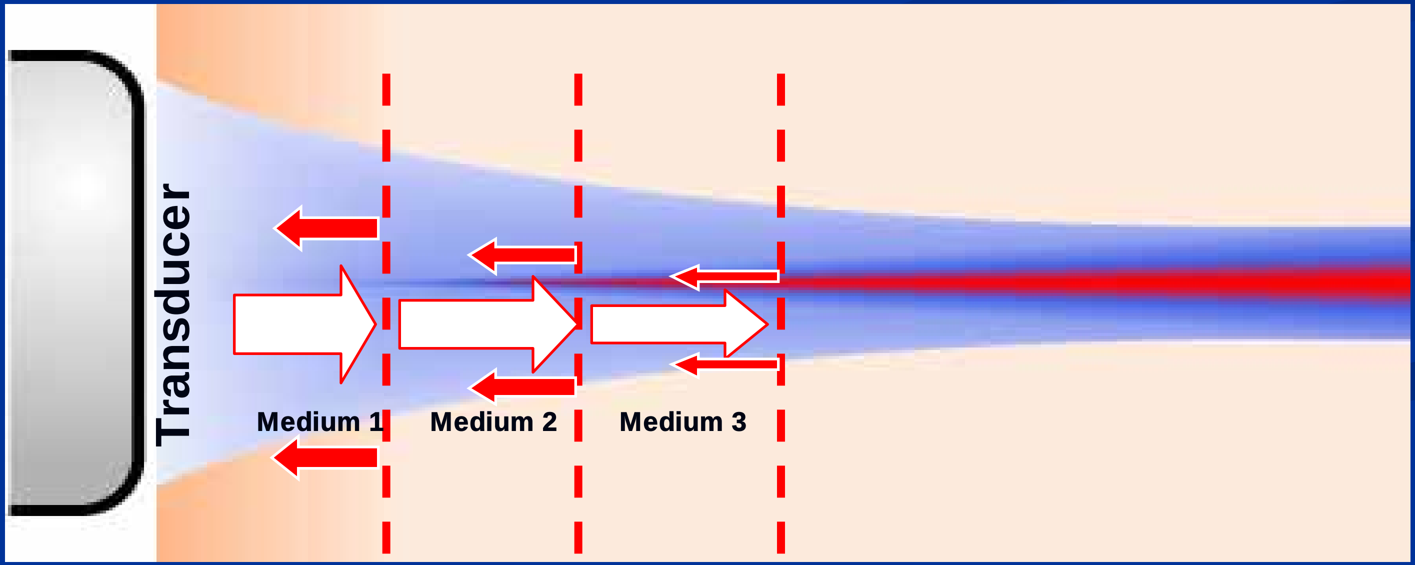
Acoustic impedance

- The **acoustic impedance** (**Z**) of a material is defined as the product of density (**p**) and acoustic velocity (**V**) of that material.
- **Ultrasound is reflected at interfaces between tissues with differing acoustic impedances (Z).**
- The speed is related to both the density and compressibility of the medium

For soft-tissue/air, soft-tissue/bone and bone/air interfaces, almost total reflection occurs

Acoustic Impedance

- Acoustic impedance (AI) is dependent on the density of the material in which sound is propagated
  - *the greater the impedance the denser the material.*
- Reflections comes from the interface of different AIs
  - greater changes of the AI = more signal reflected
  - works both ways (send and receive directions)



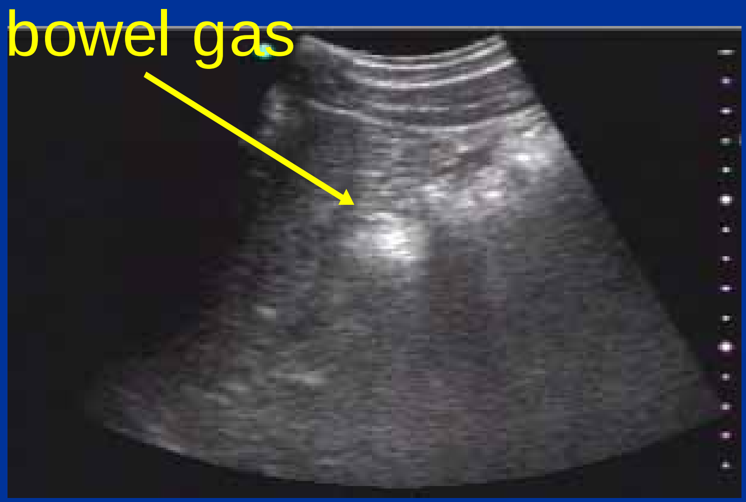
Acoustic Impedance

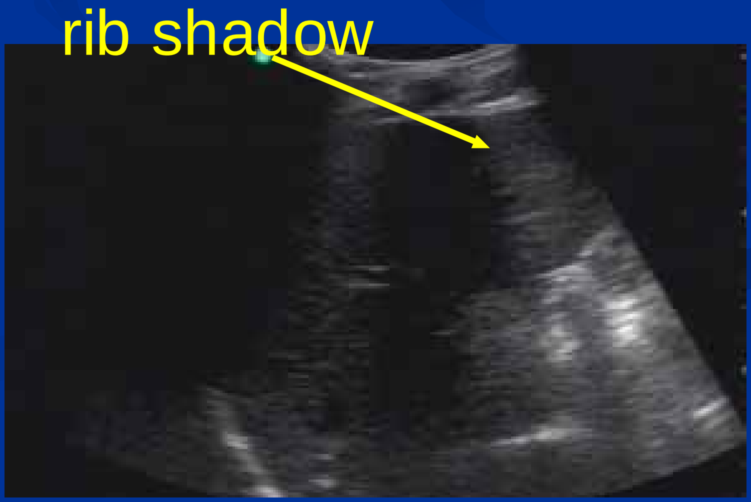
- greatest change is solid to gas (medium interface)
- 2nd greatest would be from very dense (Bone, Calcification) to mildly dense (soft tissue)

AVOID Scanning over Bone ribs, sternum, etc.

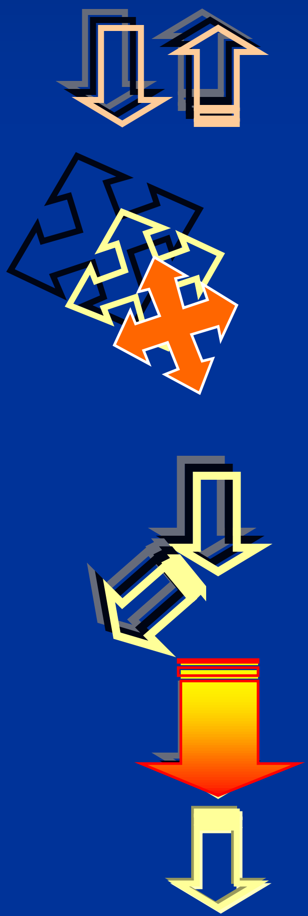
and Gas lungs or bowel

DO USE coupling agent (gel or water bath)





Attenuation: **Progressive Weakening** of the Sound Beam



Reflection

Back to the Transducer

Scatter

Reflected in Multiple Directions

Refraction

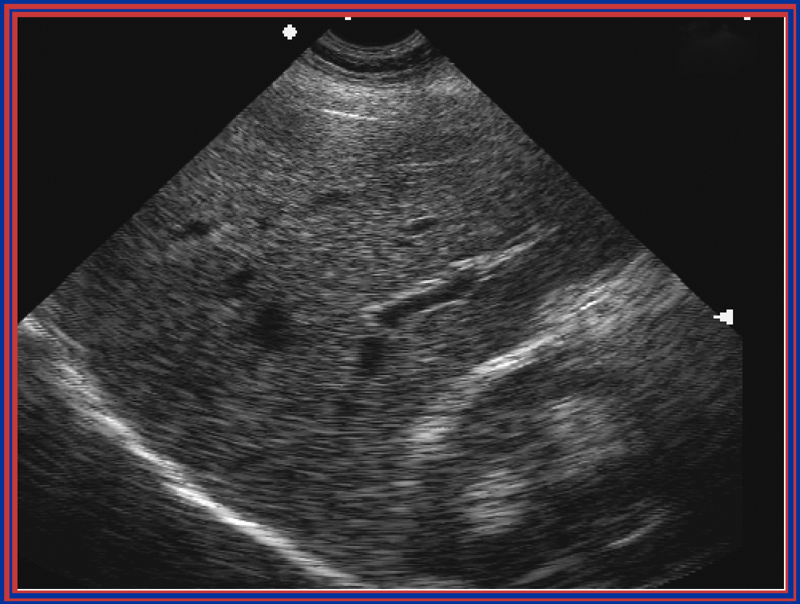
Re-direction of Part of the Sound Beam

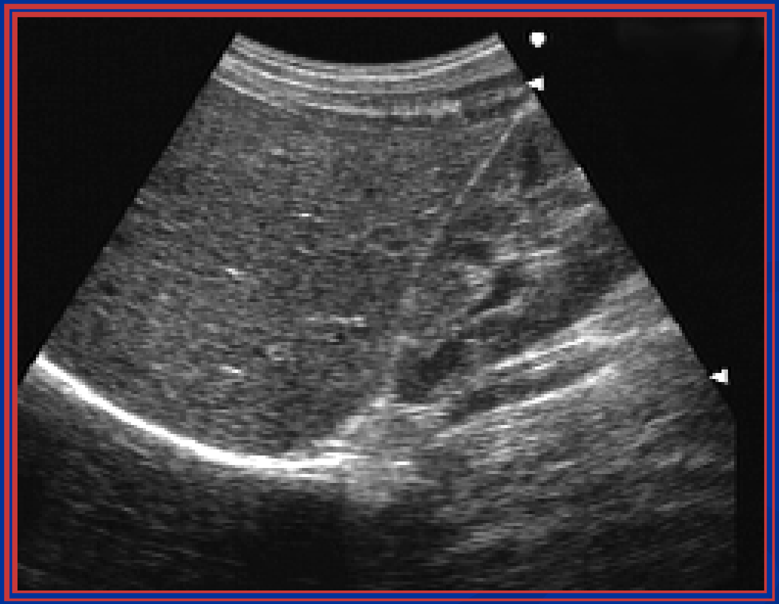
Absorption

Converted to Heat

Contrast Resolution

Systems ability to assign a different shade of gray to the returning echoes of varying amplitudes





The better the contrast resolution,

the better the axial and lateral resolution.

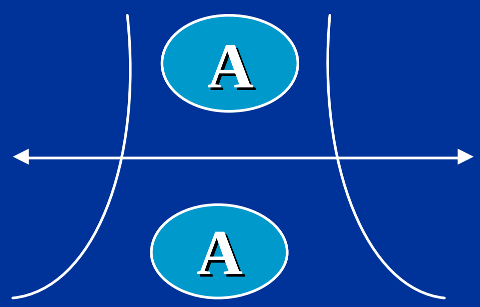
Temporal Resolution

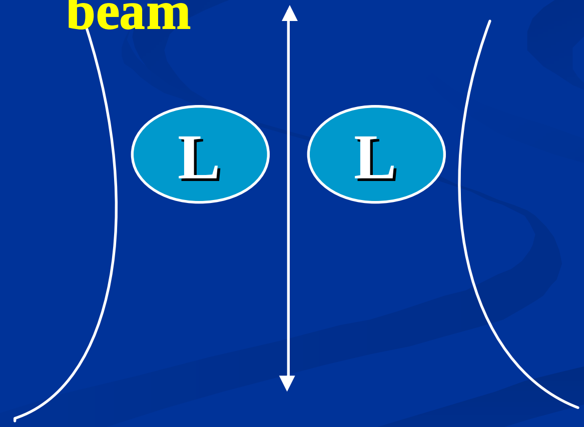
Refers to Time (tempo) and is manifested by frame rate.

- Generally, higher temporal resolution (faster frame rate) is preferred
- Tradeoffs are made to improve other resolutions

Resolution

Axial Resolution	Lateral Resolution
The ability to display two reflectors <u>along</u> the path of the beam .	**The ability to display two reflectors <u>perpendicular</u> to the beam**





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Ultrasound Guided Regional Anesthesia Workshop

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The Chinese University of Hong Kong
Prince of Wales Hsopital
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