Introduction to Ultrasound

Part 2
Principles of Ultrasound

Student Handout/ Notes

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Objectives

- Briefly describe the history of ultrasound
- Define Acoustic Impedance
- Define Acoustic Interface
- Describe what happens to a sound wave in terms of Absorption, Transmittance, Refraction and Reflection
- Describe the different types of reflection
- Describe Rayleigh Scattering
- Describe Multiple Reflections
- Define attenuation
- Discuss the concerns with the output power of an ultrasound system
- Describe Pulsed Ultrasound in terms of Pulse Repetition Frequency, Pulse Repetition Period, Pulse Duration and Duty Cycle
- Describe the relationship between frequency, penetration and resolution

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Clinical Definitions of Ultrasound

"A non-invasive diagnostic technique which provides pictures of organs and structures inside the body. It works like the sonar used by submarines, bouncing sound waves off an object and using a computer to interpret the sound returned. The interpretation of an ultrasound is very dependent upon body structure, the amount of body fat, and the skill of the operator"

"A diagnostic imaging technique which uses high-frequency sound waves and a computer to create images of blood vessels, tissues, and organs. Ultrasounds are used to view internal organs as they function, and to assess blood flow through various vessels."

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Acoustic Impedance

	Acoustic Impedance (10^5 Rayls)
Air	0.0004
Water	1.48
Fat	1.38
Blood	1.61
Kidney	1.62
Soft Tissue, Average	1.63
Liver	1.65
Muscle	1.70
- Along Fibers	
- Across Fibers	
Bone	7.80

Acoustic impedance is the resistance a material presents to the passage of a sound wave through it.

Generally speaking, the more dense, or hard, a medium is, the greater its acoustic impedance.

Acoustic Impedance is measured in Rayls, named after Lord Rayleigh, one of the pioneers in the study of sound and light properties.

Soft Tissue Average – the average impedance of all soft tissues in the body. Used as a constant.

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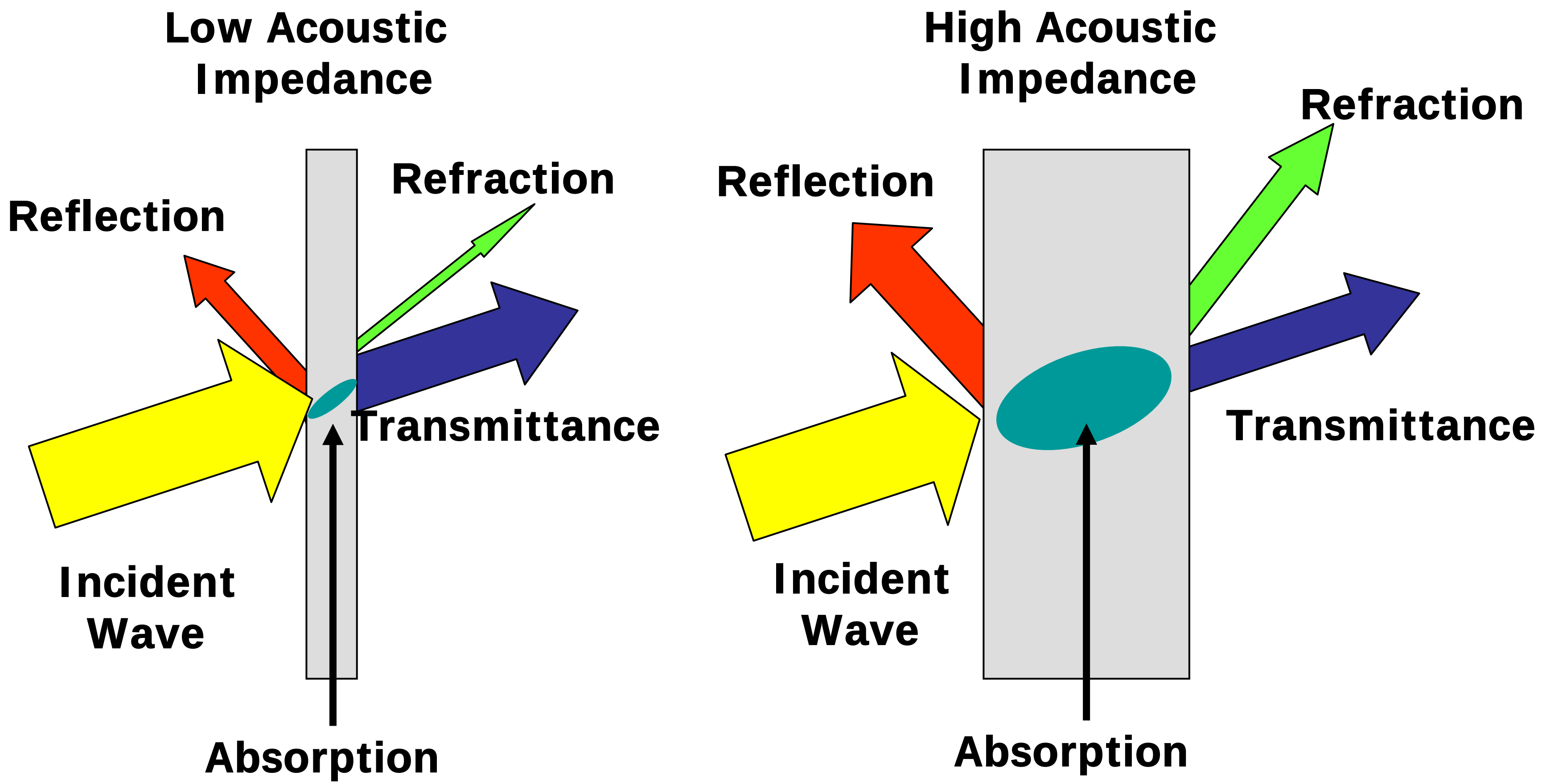

The value of the acoustic impedance at the interface determines how much reflection, refraction, transmittance and absorption there is.

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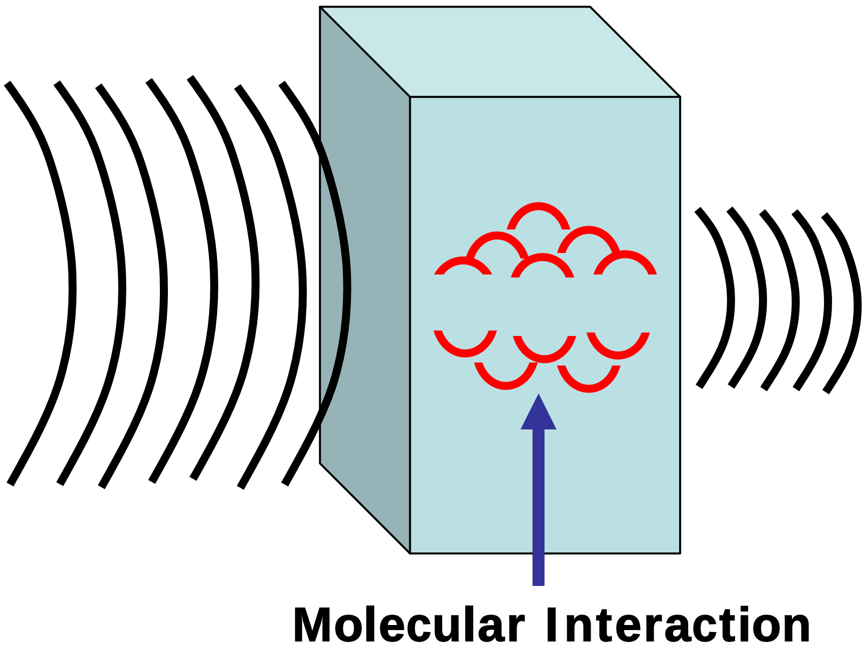
Absorption Loss



As sound or light waves pass through a medium, some of the wave collides with the molecules within the medium and is given off as heat.

Typically, the more pure, meaning the more alike, the molecules of a medium are, the less will be absorbed by the medium.

Absorption is also directly proportional to frequency in that the higher the frequency of the ultrasonic wave, the more it will be absorbed as it passes.

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The Speed of Sound

	Velocity (meters/second
Air	330
Water	1480
Fat	1450
Blood	1570
Kidney	1560
Soft Tissue, Average	1540
Liver	1550
Muscle	1580
- Along Fibers	
- Across Fibers	
Bone	4080

The denser the tissue of an organ is, the faster sound travels through it.

Average velocity through soft tissue = 1540 meters/second – SOFT TISSUE AVERAGE

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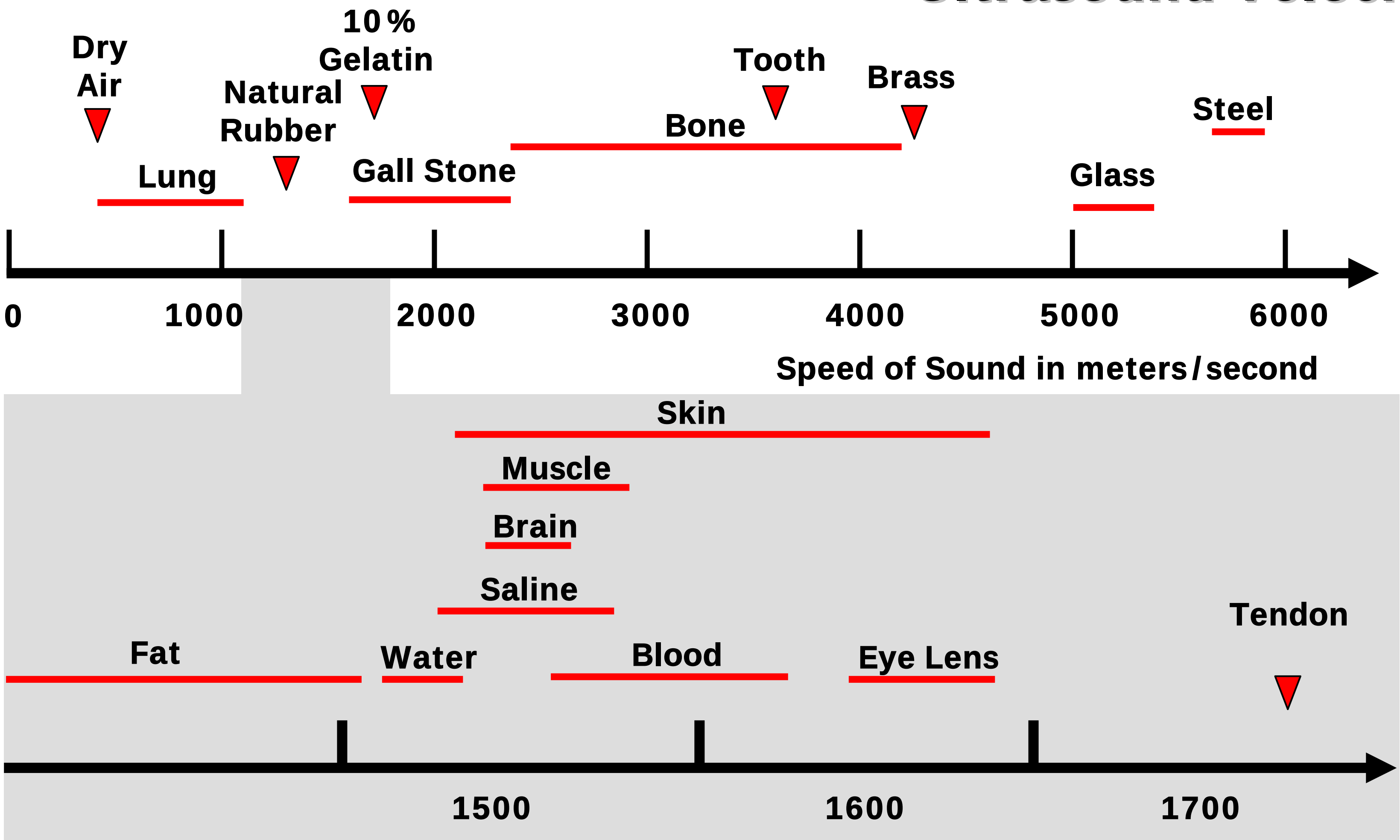
Ultrasound Velocities



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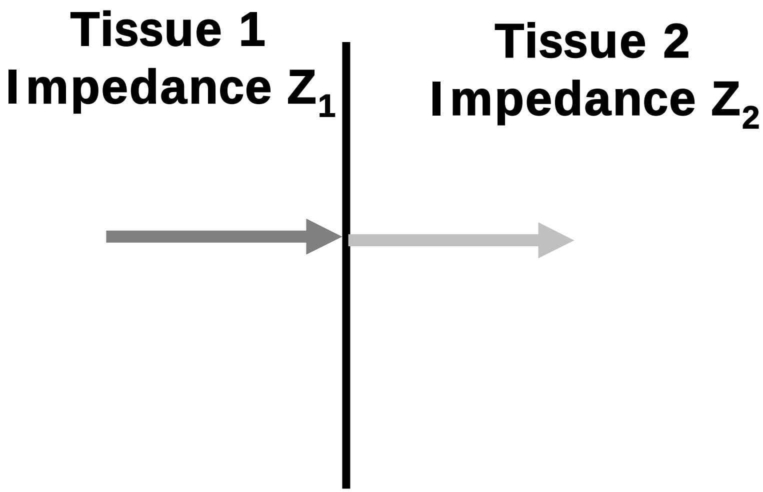
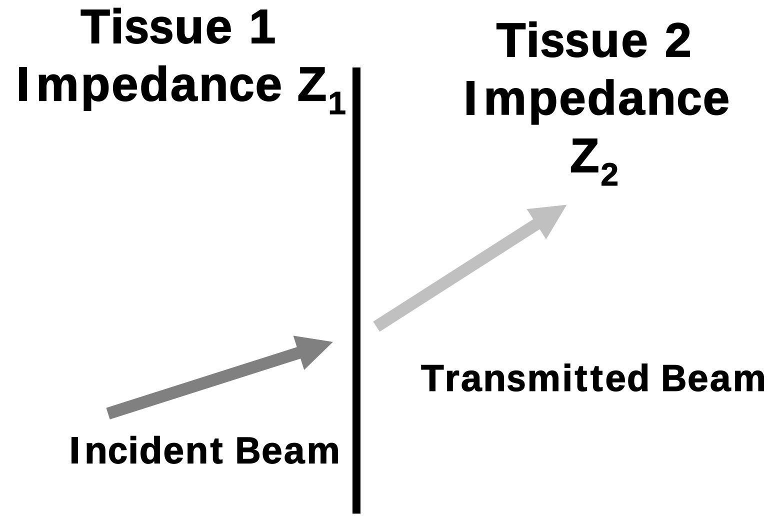
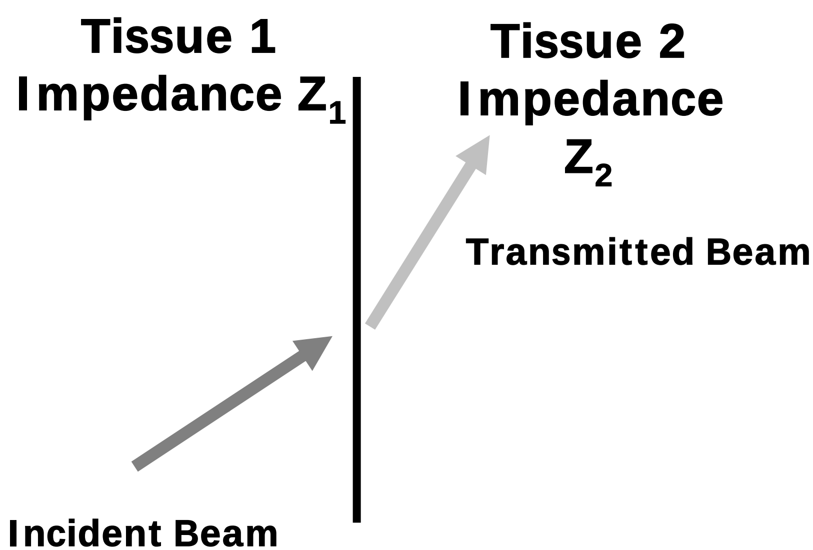
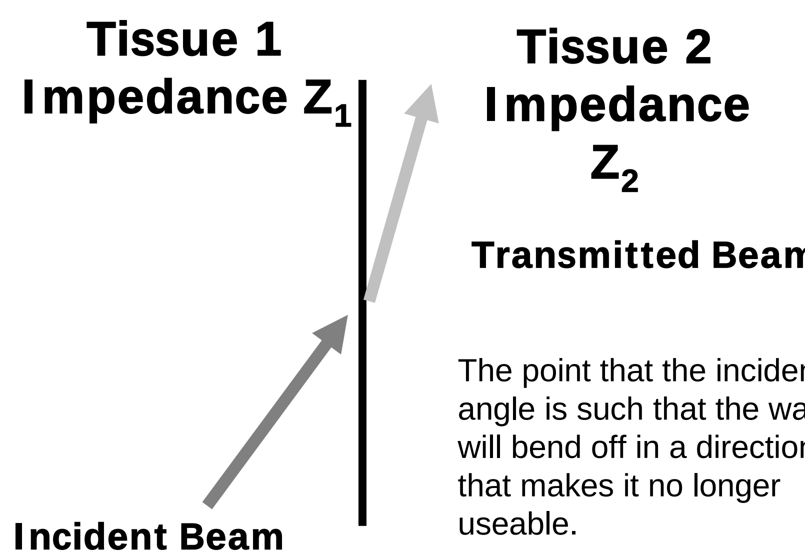






Critical Angle



The point that the incident angle is such that the wave will bend off in a direction that makes it no longer useable.

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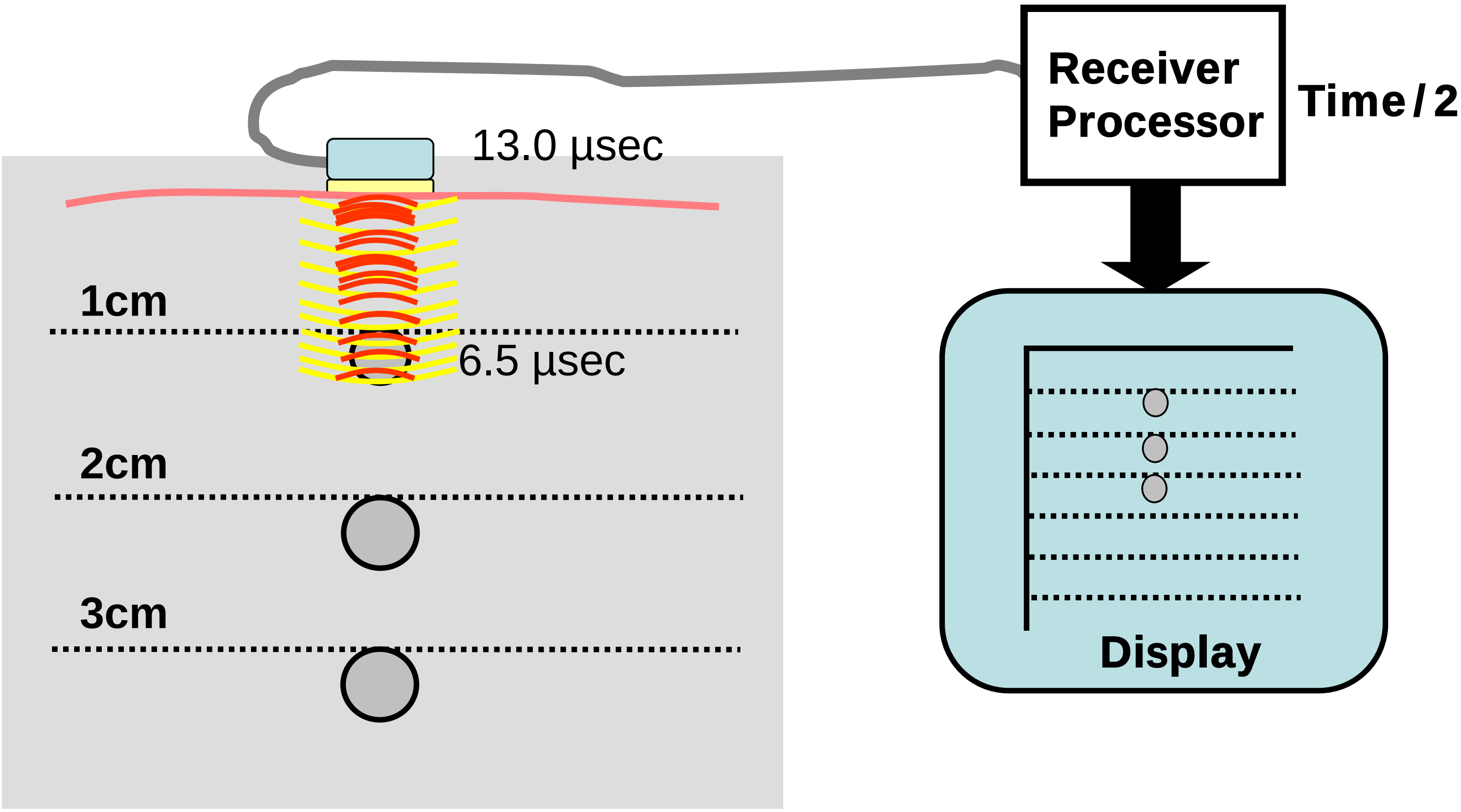
1540 meters/ second
= 154000 centimeters/ second
= .154 centimeters/ µsecond
= 1 centimeter in 6.5 µseconds



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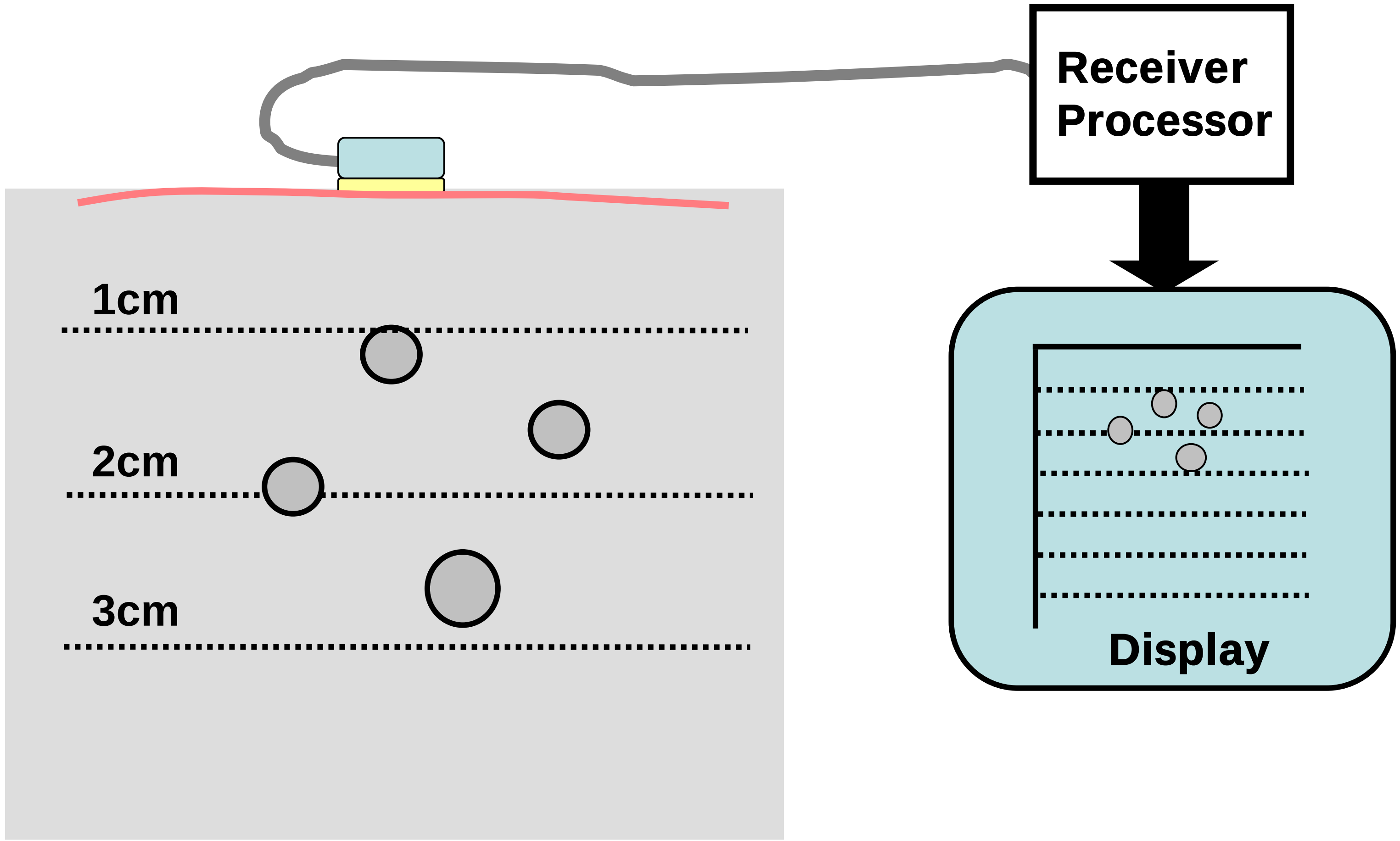

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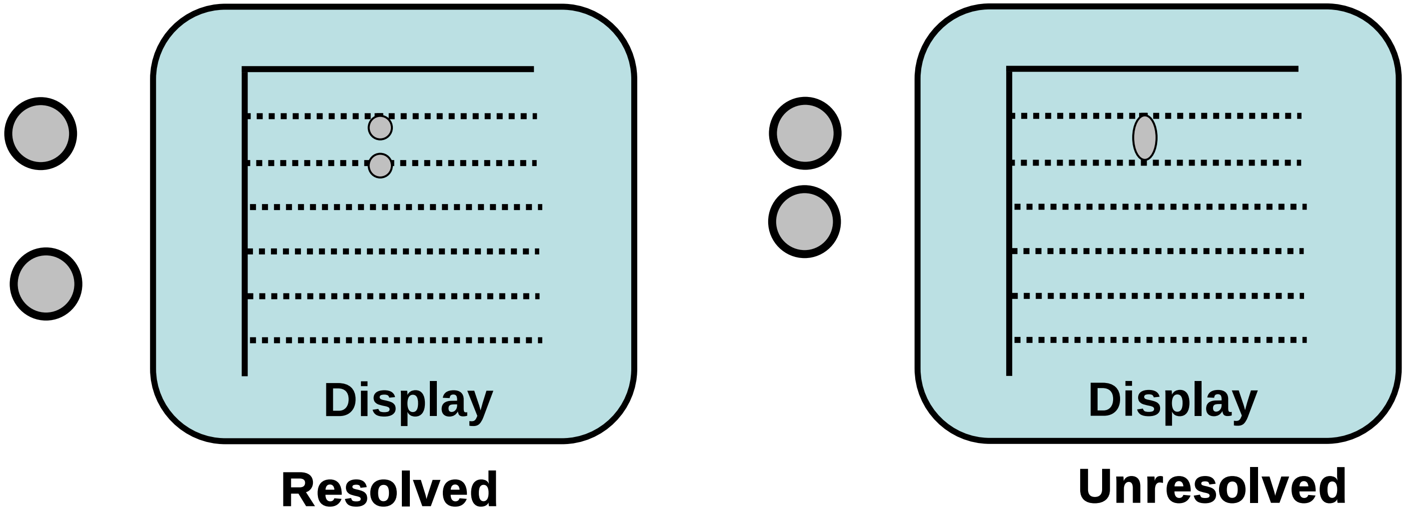
Axial Resolution



A function of the transducer frequency

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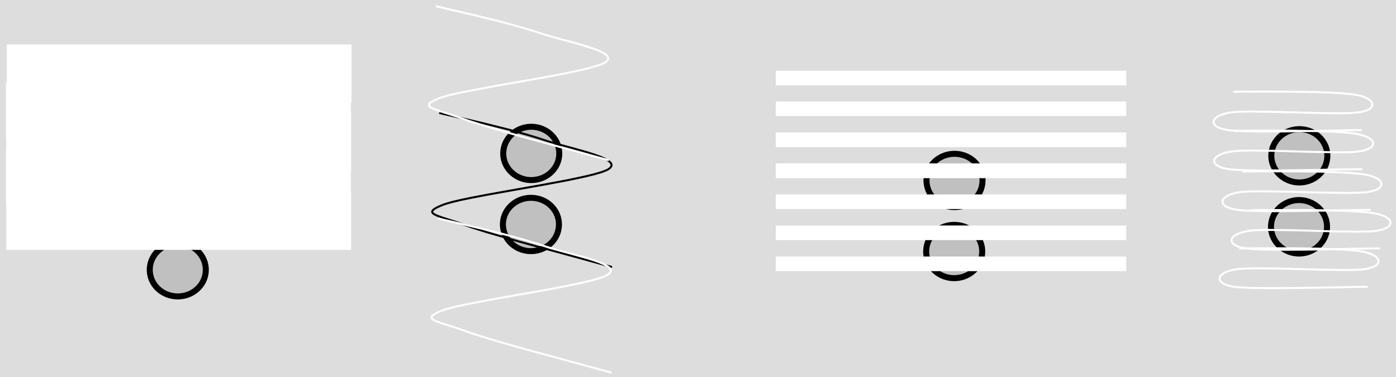

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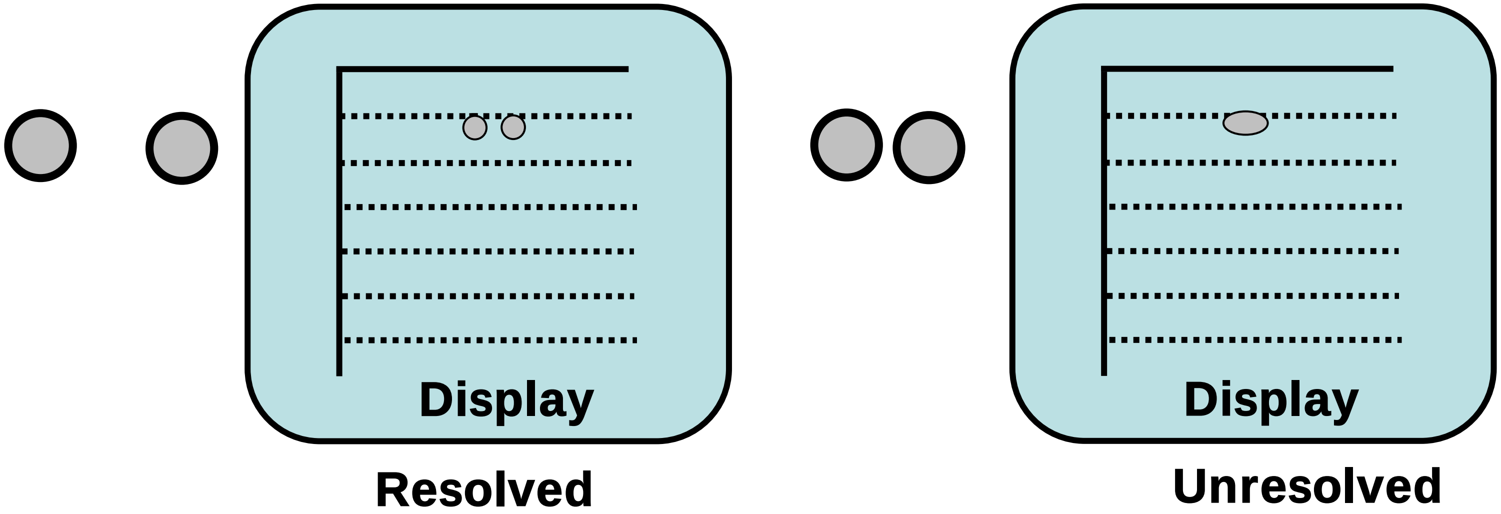
Lateral Resolution



A function of beamformer accuracy, element pitch, aperture size, transducer frequency and element height.

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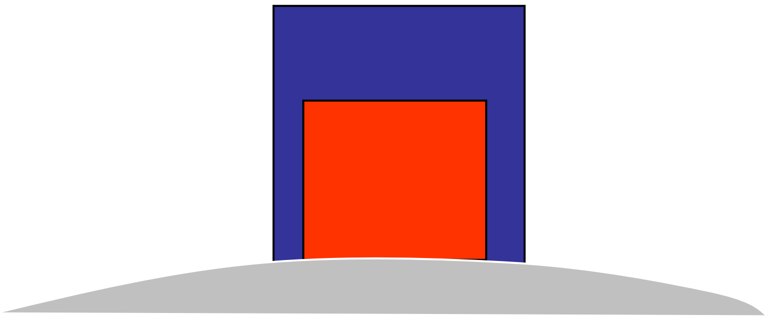


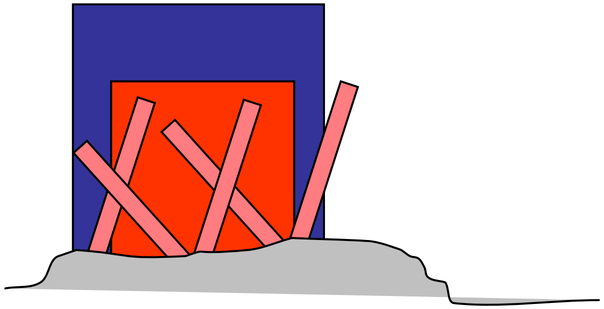
Specular Reflection

When our transmitted wave comes into contact with an object or acoustic interface that is of the same relative size or larger than the wavelength of our wave AND the surface is smooth, our angle of reflection is exactly equal to our angle of incidence.

If the angle of incidence is zero degrees, all of the reflection will be returned to our transducer.

This is called SPECULAR reflection

The largest specular interface in the human body is the diaphragm.



Diffuse Reflection

If the surface is irregularly shaped, we'll actually get multiple reflections going in a variety of different directions.

The Angle of Reflection equals Angle of Incidence theory no longer applies.

Some of our reflected wave will be returned to our transducer, but some of it will be lost to these smaller, irregular reflections.

This is called DIFFUSE reflection.

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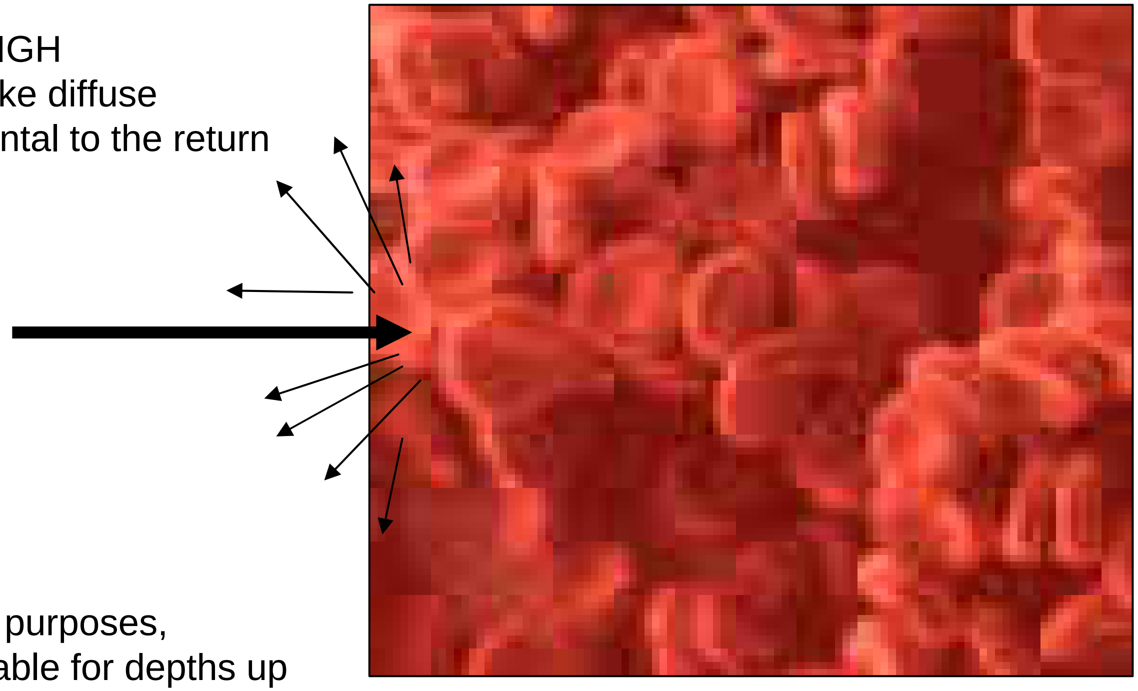
When the sound wave comes into contact with something that is smaller that the wavelength, it can produce multiple reflections as well, sending portions of the sound wave in all different directions.

This is called RAYLEIGH SCATTERING and, like diffuse reflections, is detrimental to the return echo.

Red Blood Cells



Rayleigh Scattering

In fact, for diagnostic purposes, ultrasound is only usable for depths up to about twenty two to twenty four centimeters, which is about seven or eight inches.

The effects of absorption, diffuse reflection and Rayleigh Scattering is called ATTENUATION.

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Attenuation

	Attenuation (dB/cm at 1 MHz)
Air	**12**
Water	**0.002**
Fat	**0.63**
Blood	**0.18**
Kidney	**1.0**
Soft Tissue, Average	**.7**
Liver	**.94**
Muscle	**1.70**
- Along Fibers	**1.3**
- Across Fibers	**1.3**
Bone	**5**

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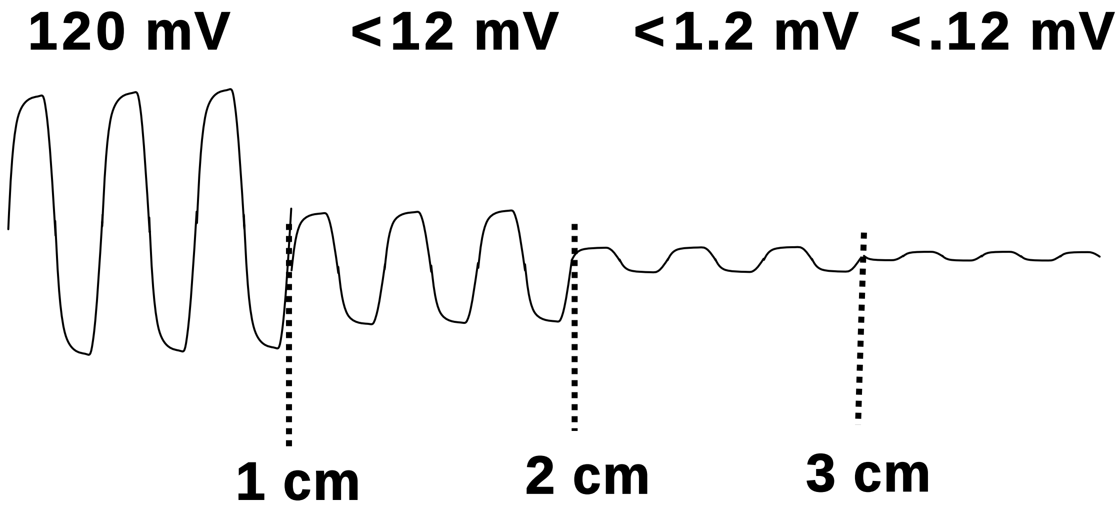
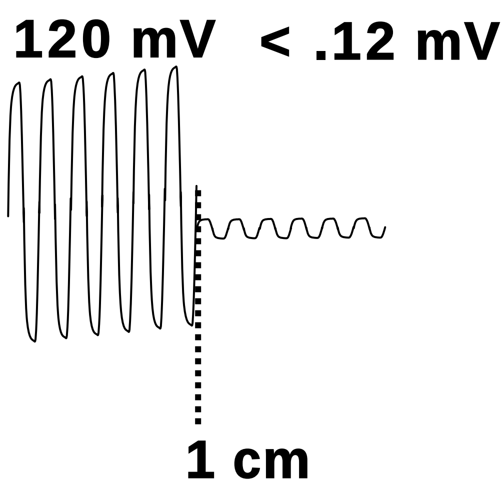
-12 dB/cm/MHz 1.0 MHz probe



-12 dB/cm/MHz 10 MHz probe



Air’s high attenuation factor means that the sound wave literally dies out within inches of our transducer face.

The Soft Tissue Average is minus point seven dB/centimeter/ megahertz.

For ease of calculation and explanation, we use the same value as the kidney, or minus one dB/centimeter/ megahertz.

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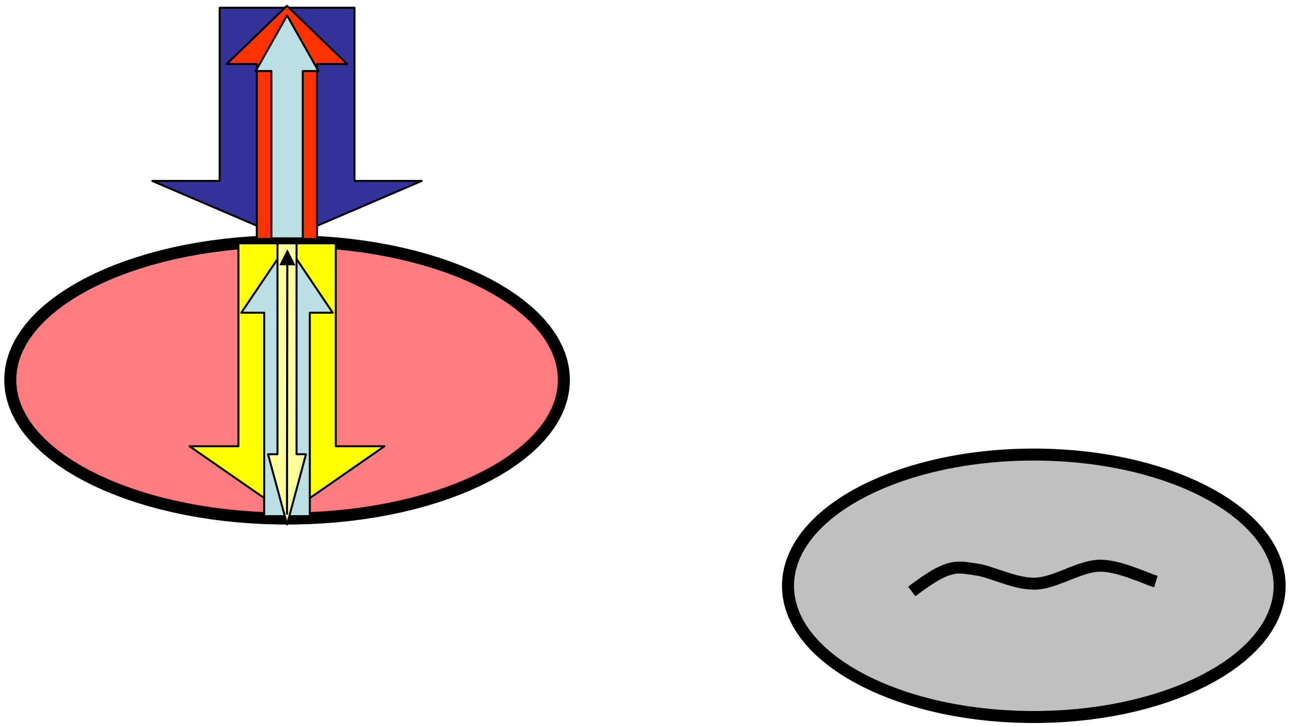
Multiple Wave or Reverberation Artifact



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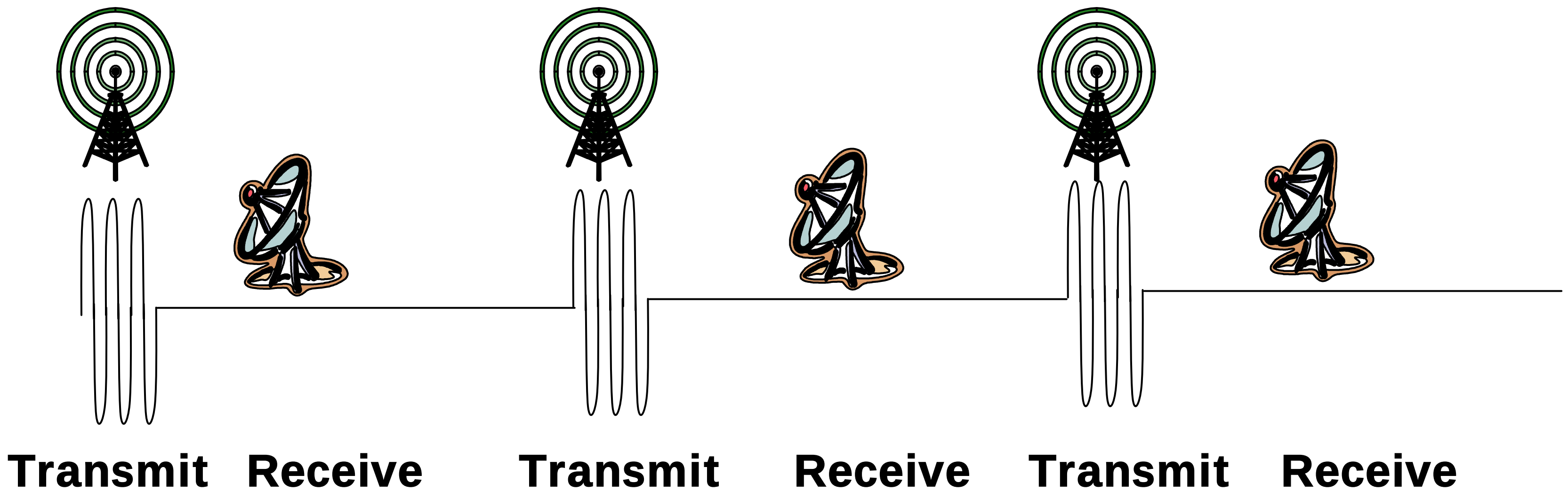

Pulse Repetition Frequency (PRF) – number of pulses that occur in 1 second (Hz)

Pulse Repetition Period (PRP) – time from the beginning of one pulse to the of the next (msec)

Pulse Duration – time it takes for one pulse to occur (in msec).

Duty Cycle (or Duty Factor) – the fraction of time that the pulse is being generated divided by the total Pulse Repetition Period (as a fraction or percentage)

- **If the Pulse Repetition Period is 50 milliseconds and the pulse is active for 1 millisecond, the Duty Cycle would be .02 or 2%.**

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Two Big Concerns With Ultrasound

A.I.U.M. – American Institute of Ultrasound in Medicine
FDA – Food and Drug Administration

MI – Mechanical Index
TI – Thermal Index

The heat buildup from **ABSORPTION**. It is relatively minor, but it DOES exist; and, believe it or not, it’s most prominent around or in the bone.

The second is **CAVITATION**. There is continuous transition as long as the amplitude or "loudness" of the sound is relatively low. As amplitude is increased, however, the magnitude of the negative pressure in the areas of rarefaction eventually becomes sufficient to cause the liquid to fracture because of the negative pressure. Cavitation "bubbles" are created at sites of rarefaction as the liquid fractures or tears because of the negative pressure of the sound wave in the liquid. As the wave fronts pass, the cavitation "bubbles" oscillate under the influence of positive pressure, eventually growing to an unstable size. Finally, the violent collapse of the cavitation "bubbles" results in implosions, which cause shock waves to be radiated from the sites of the collapse.

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As Frequency ↓ Penetration ↑ and Resolution ↓

As Frequency ↑ Penetration ↓ and Resolution ↑

-1 dB/ cm/ mHz Attenuation Rule

1 mHz probe will lose 10 dB at 10 cm
7 mHz probe will lose 70 dB at 10 cm
10 mHz probe will lose 100 dB at 10 cm

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Notes

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