

Sonography – Basic Principles

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Sonography

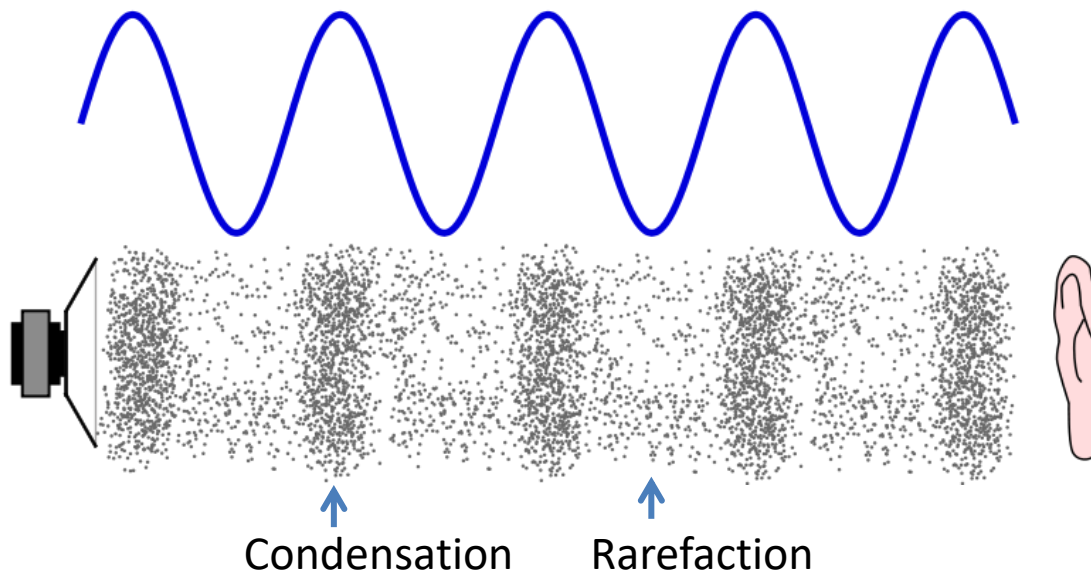
Sonus (gr.) = Sound

Graphēin (gr.) = to write

Medical imaging with ultrasound
is called sonography.

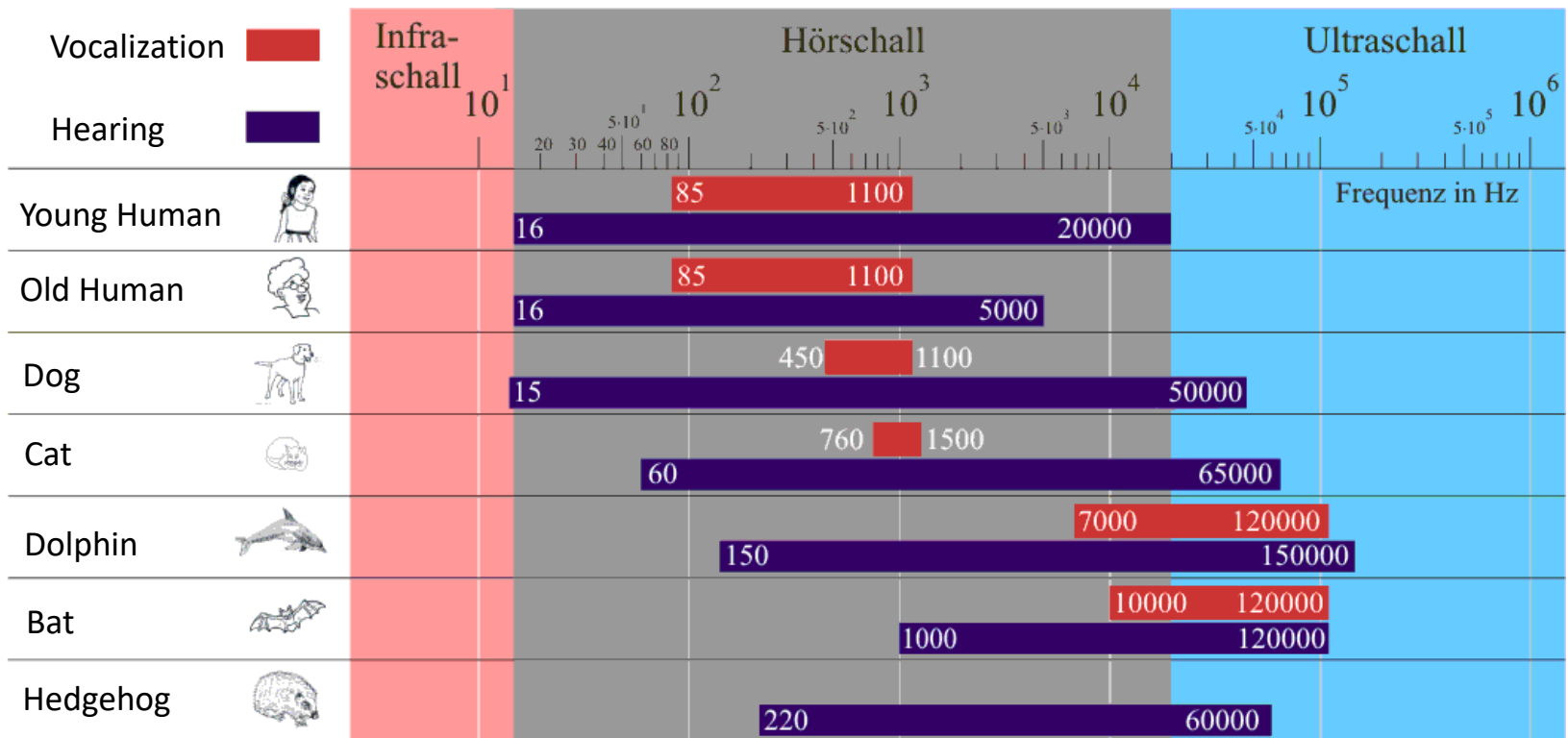
What is Sound ?

- Mechanical and Longitudinal waves that can travel a distance using a media.
- Cannot travel through Vacuum.



Frequency

- Number of cycles per second
- Units are Hertz



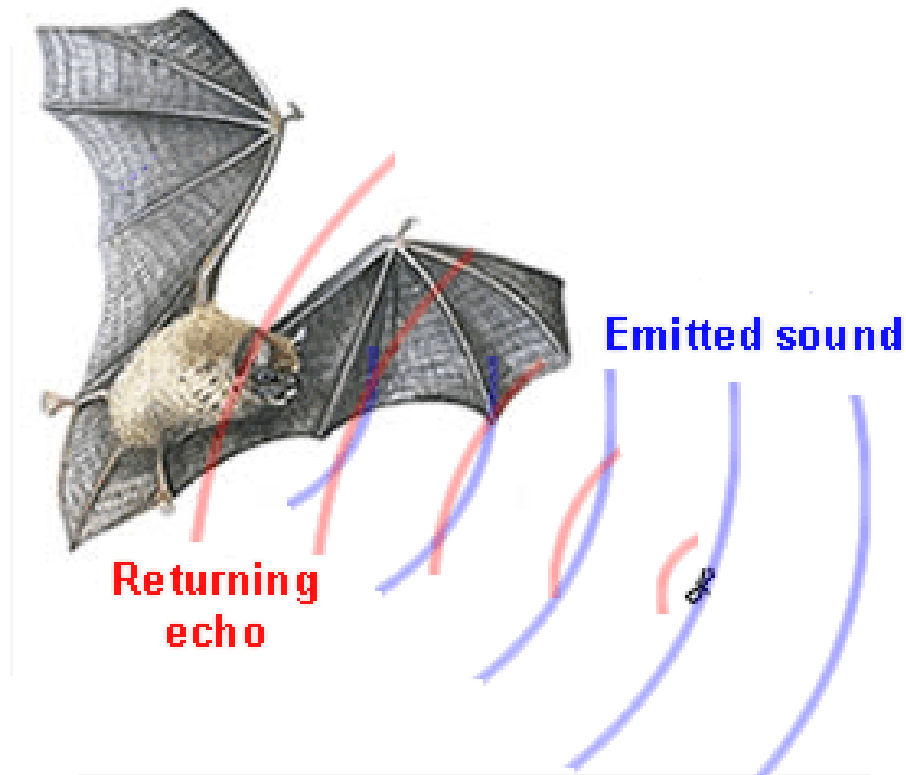
What is Ultrasound?

Ultrasound is a mechanical, longitudinal wave with a frequency exceeding the upper limit of human hearing, which is 20,000 Hz or 20 kHz.

Ultrasound imaging frequency range: 2-20 Mhz.

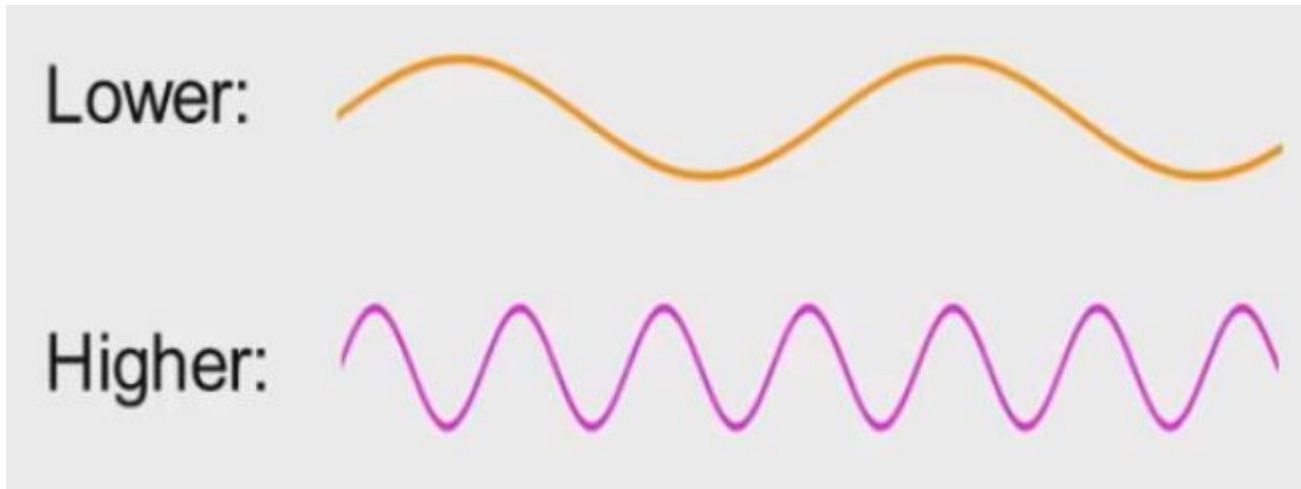
How Ultrasound works...

- How does an ultrasound machine make an image ?

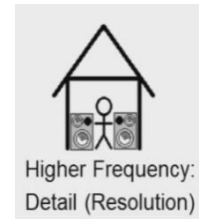
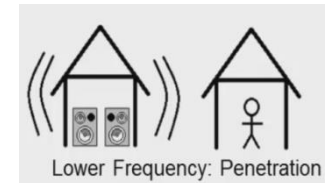


Frequency

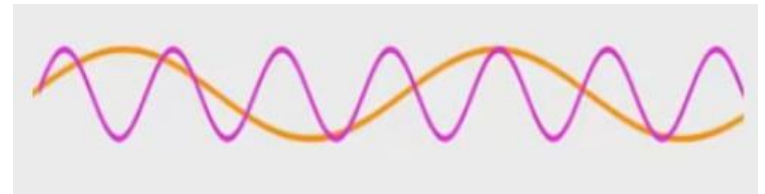
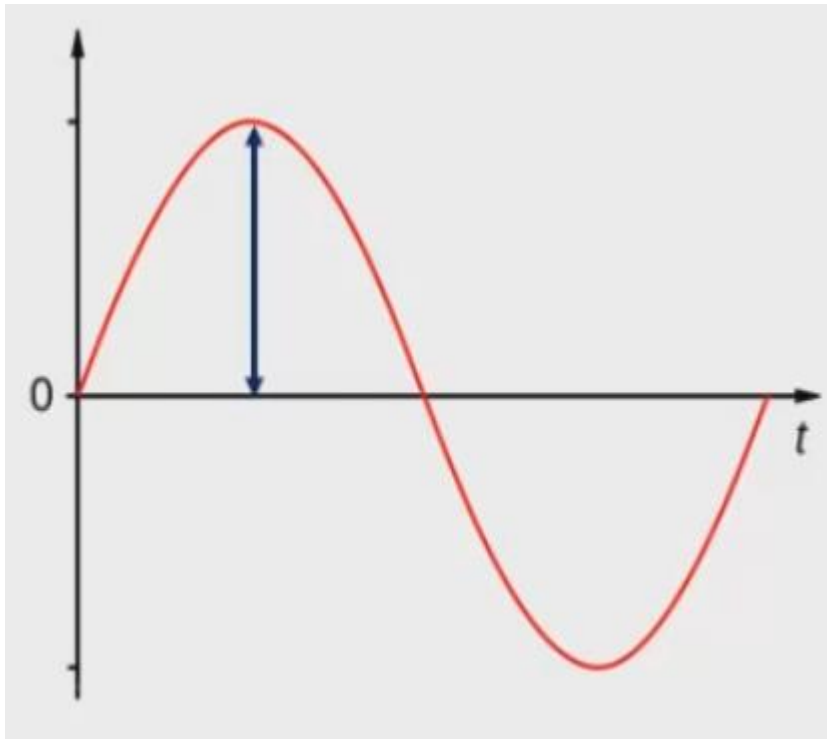
Lower the frequency: higher the penetration and lower the resolution



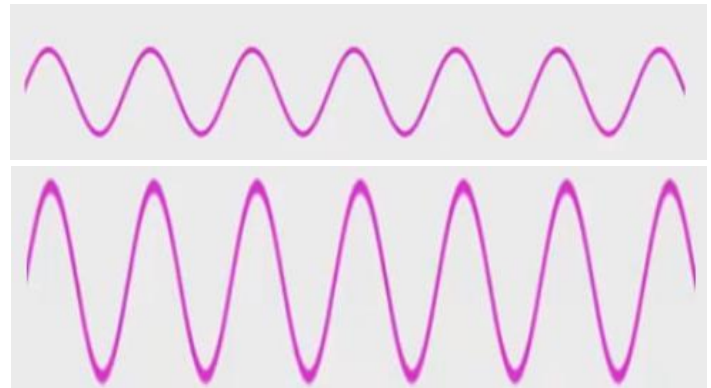
Higher the frequency: lower the penetration and higher the resolution



Amplitude



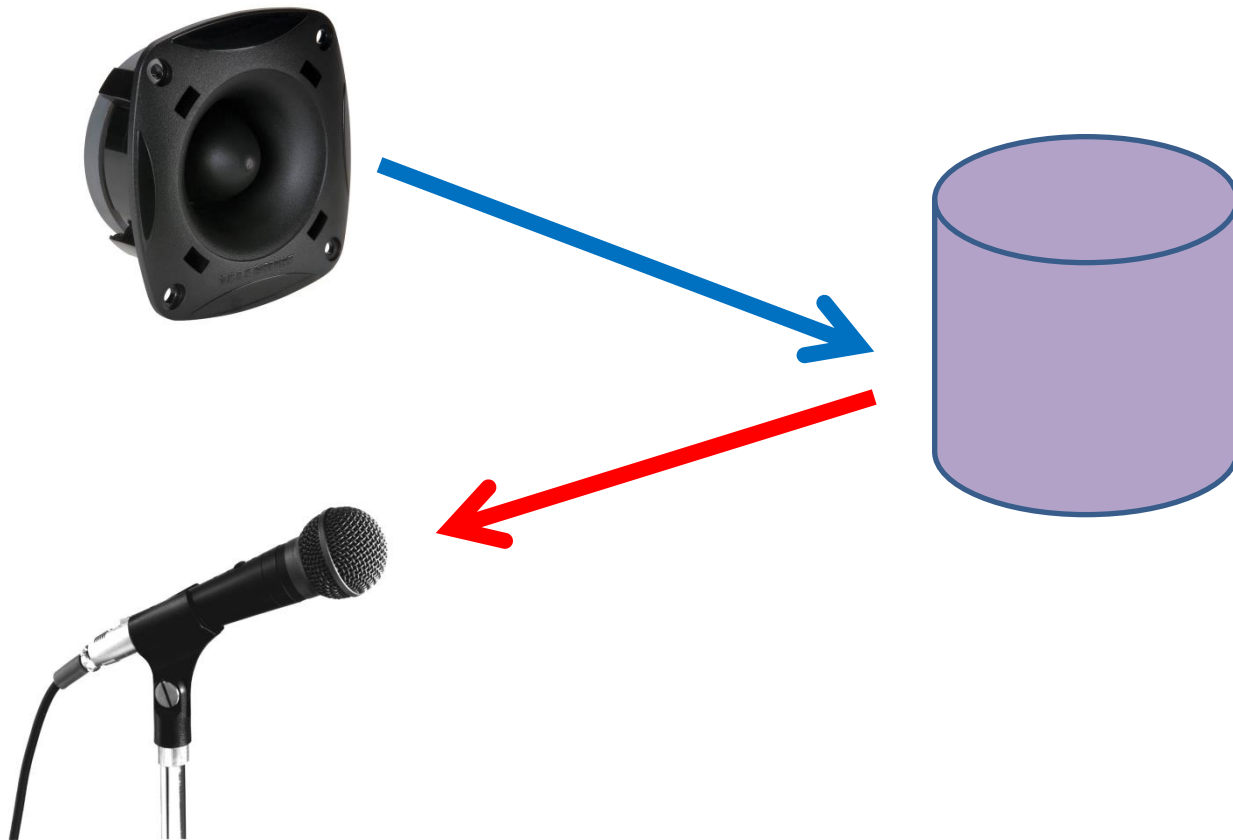
Irrespective of the Freq the Amp remains constant



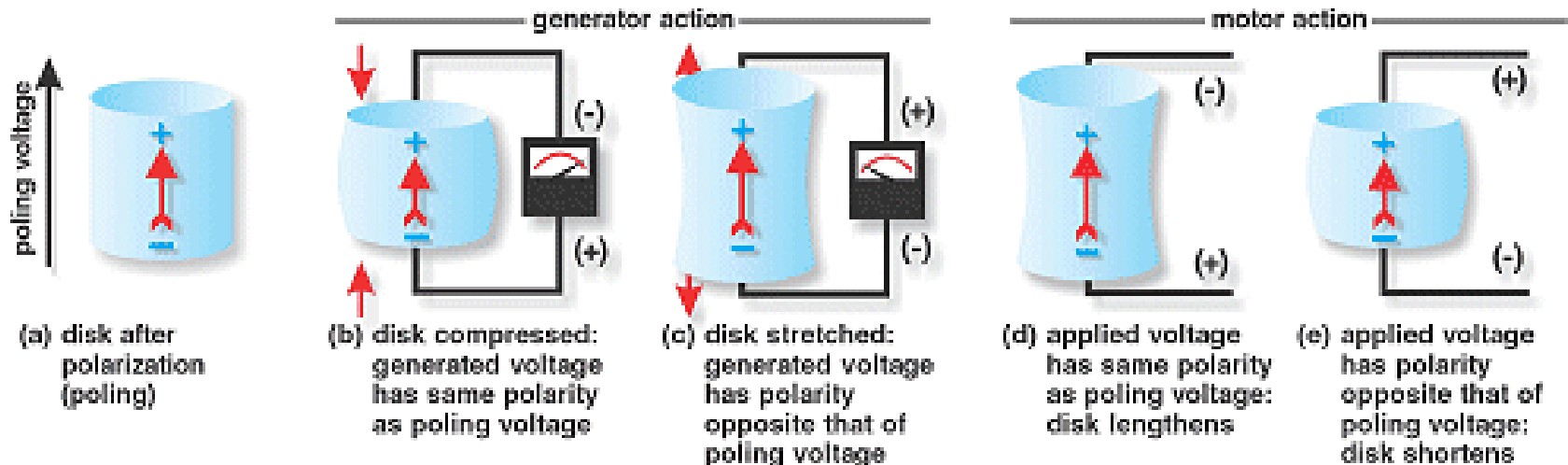
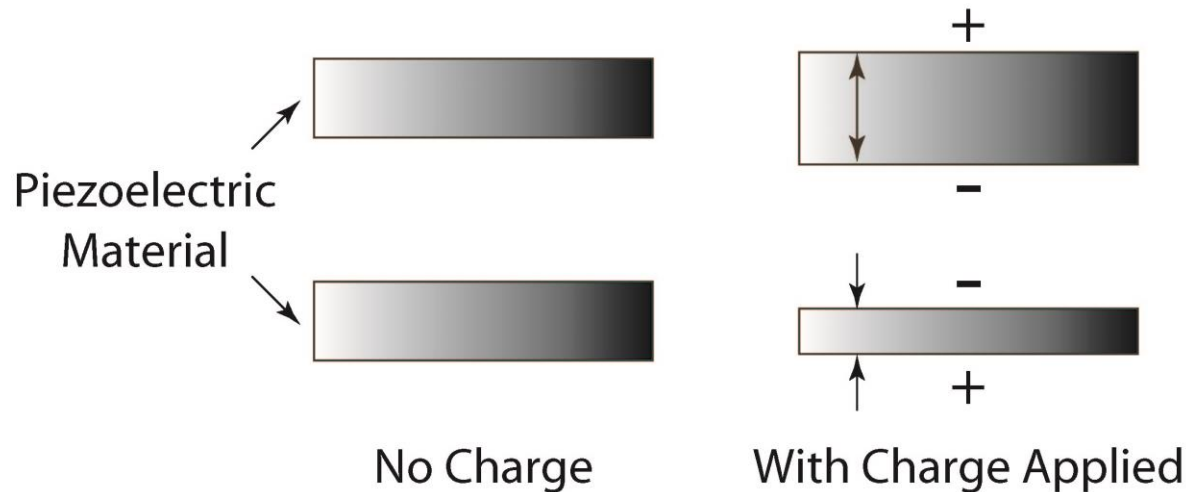
Velocity

- Speed at which a sound wave travels through a medium (cm/sec)
- Determined by density and stiffness of media
 - Slowest in air/gas
 - Fastest in solids
- Average speed of ultrasound in body is 1540 m/sec

Setup

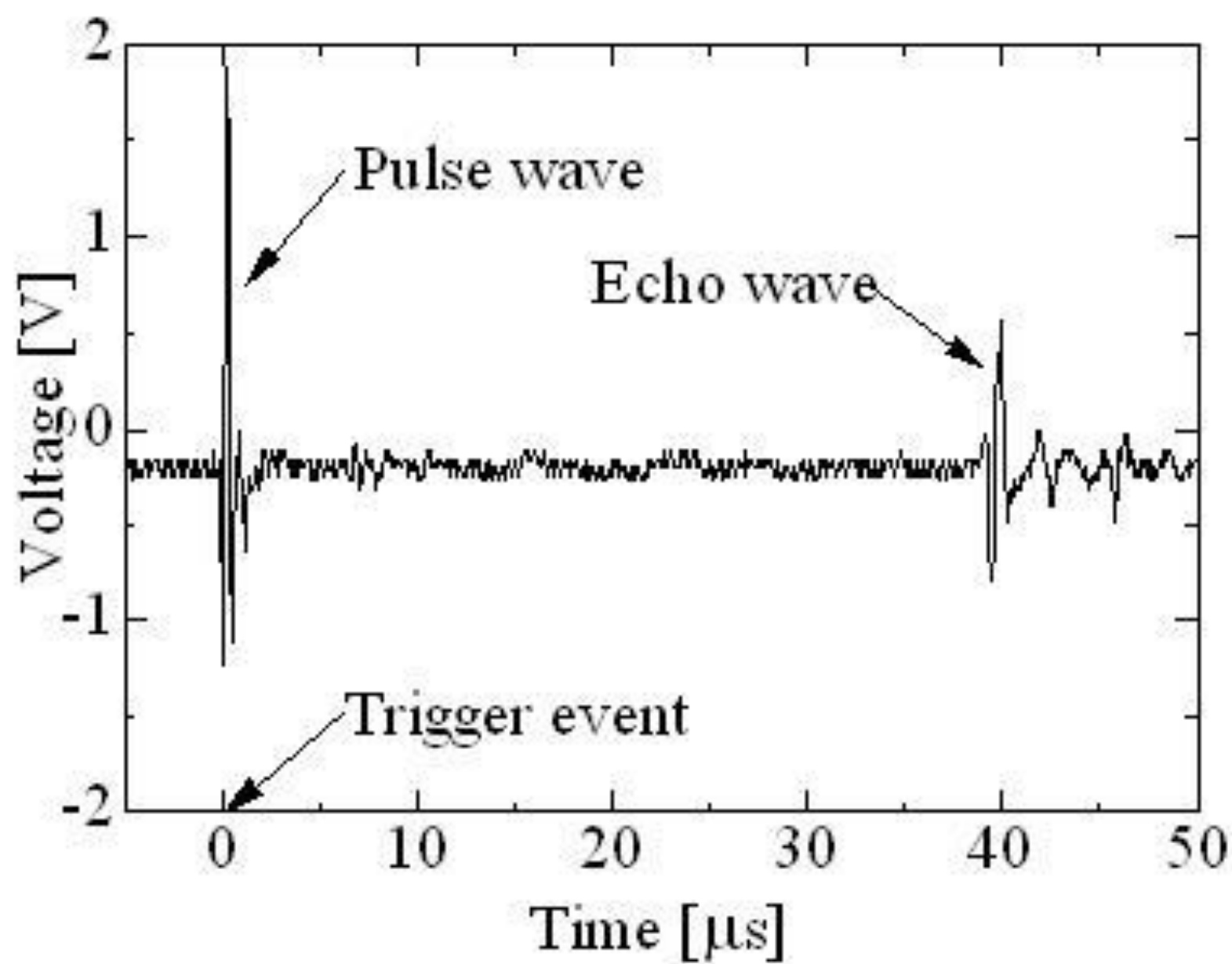


Piezoelectric Effect



Pulse-Echo Method

- Ultrasound transducer produces “pulses” of ultrasound waves
- These waves travel within the body and interact with various tissues
- The reflected waves return to the transducer and are processed by the ultrasound machine
- An image which represents these reflections is formed on the monitor



How is an image formed on the monitor?

- Each reflected wave is represented by a dot
- The **position** of the dot represents the depth from which the echo is received
- The **brightness** of the dot represents the amplitude of the returning echo
- These dots are combined to form a complete image

Reflected Echoes

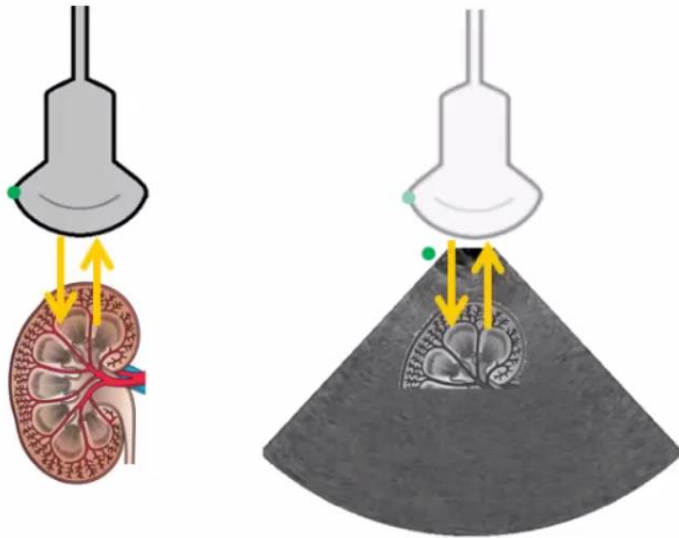
- Strong Reflections = White dots
 - Pericardium, calcified structures, diaphragm
- Weaker Reflections = Grey dots
 - Myocardium, valve tissue, vessel walls, liver
- No Reflections = Black dots
 - Intra-cardiac cavities, gall bladder

Position of Reflected Echoes

- How does the system know the depth of the reflection?
- TIMING
 - The system calculates how long it takes for the echo to return to the transducer
 - The velocity in tissue is assumed constant at 1540m/sec

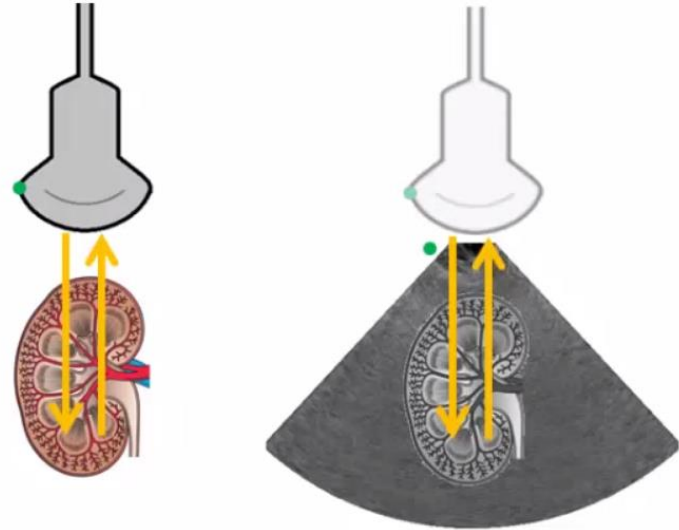
Distance ~ Time

Near Field Imaging



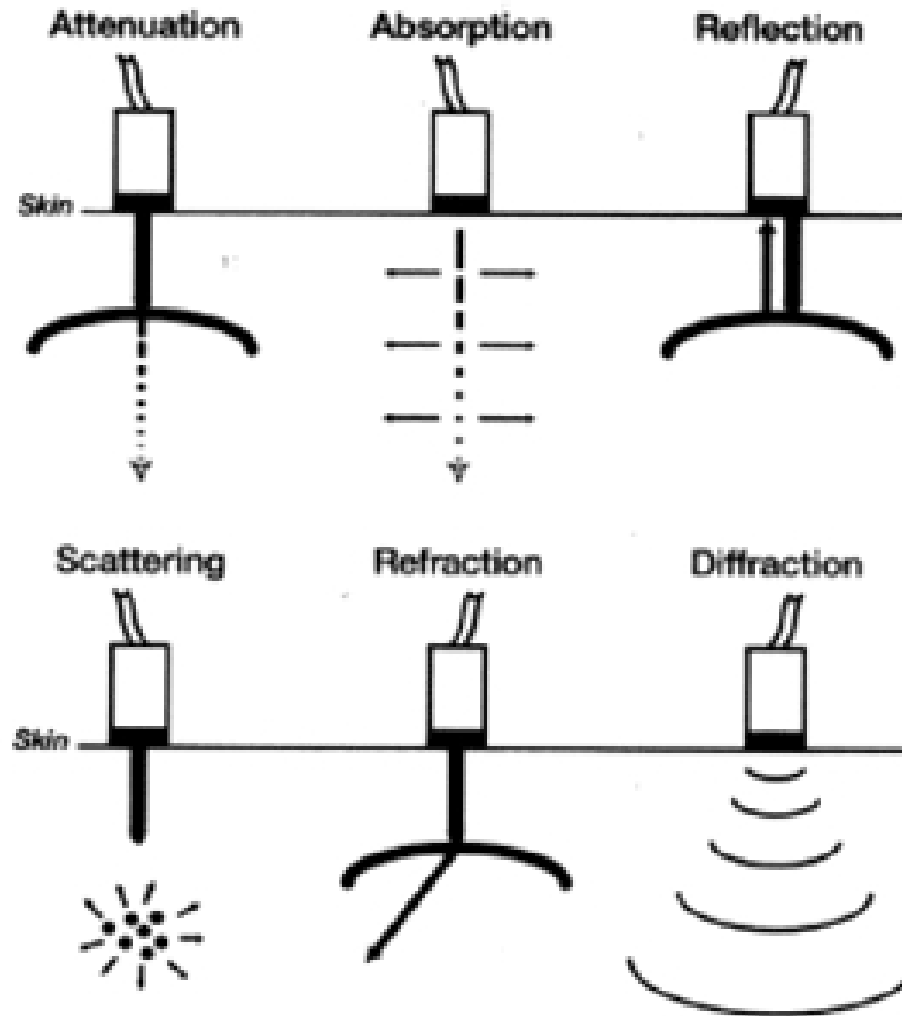
*Tissues closer appear on
top and faster the waves
return*

Far Field Imaging



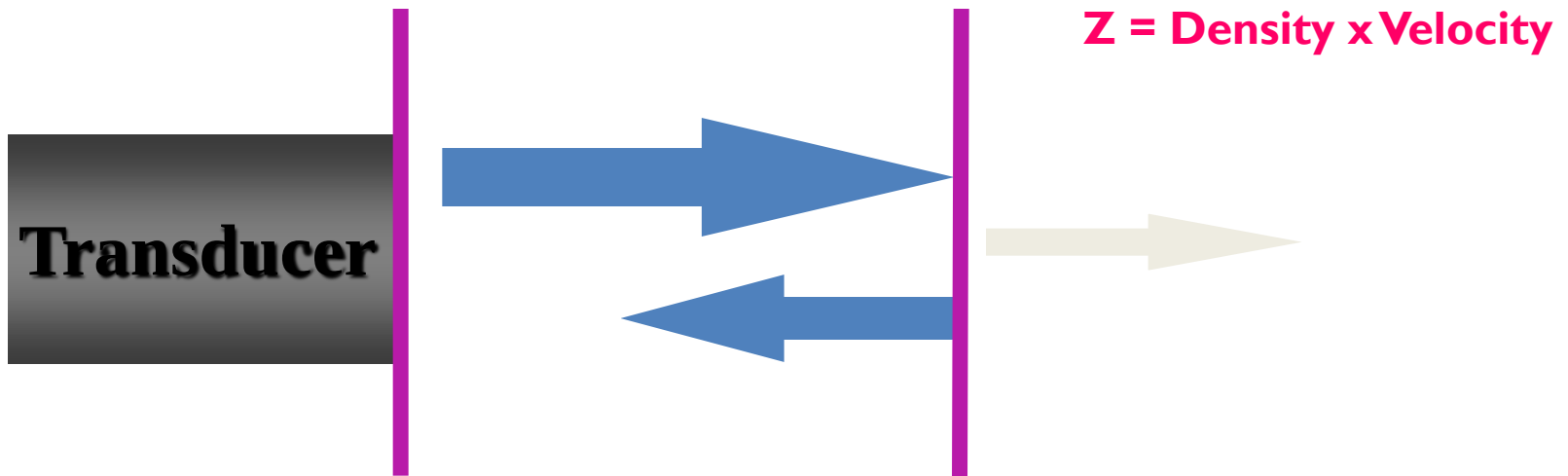
*Tissues further appear at
the bottom & slower the
waves return*

Interactions of Ultrasound with tissue



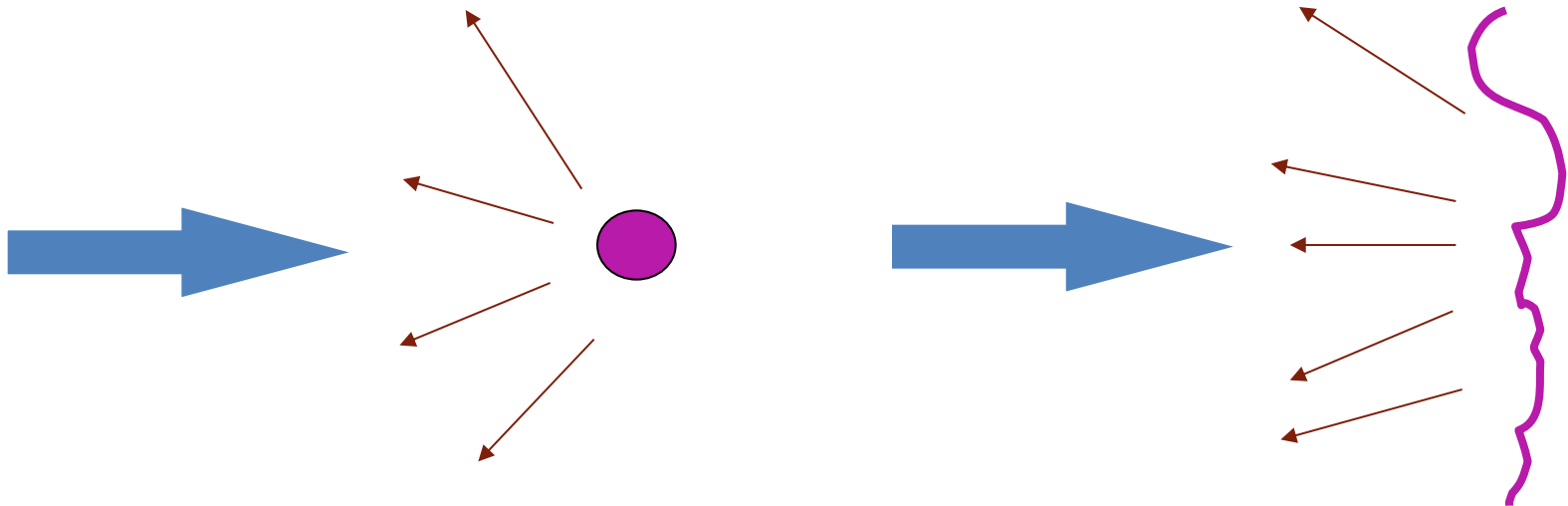
Reflection

- Occurs at a boundary between 2 adjacent tissues or media
- The amount of reflection depends on differences in acoustic impedance (z) between media
- The ultrasound image is formed from reflected echoes



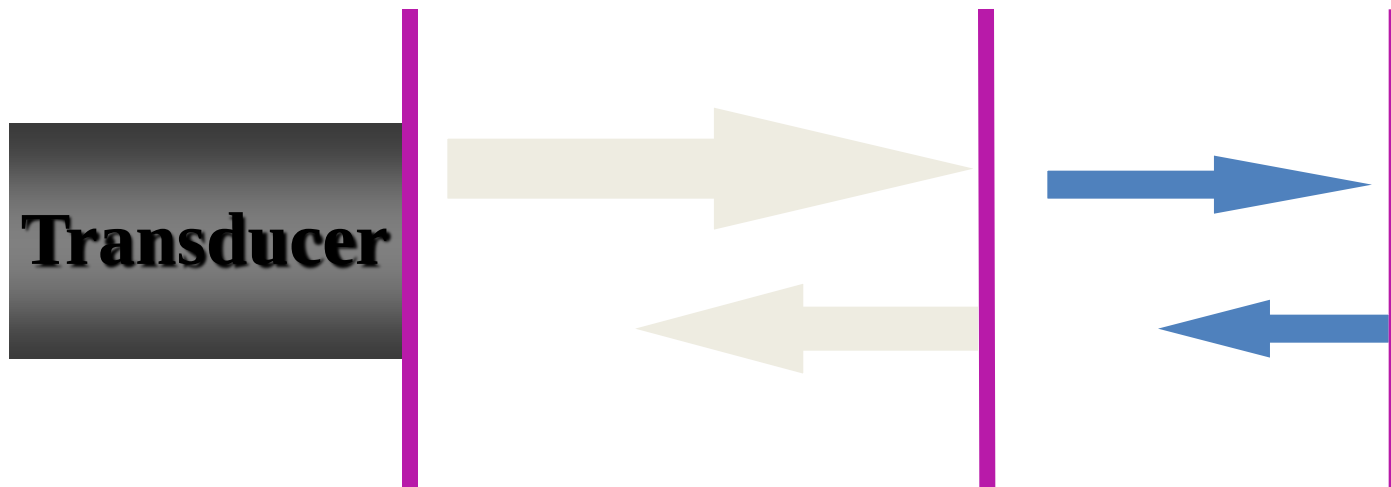
Scattering

- Redirection of sound in several directions
- Caused by interaction with small reflector or rough surface
- Only portion of sound wave returns to transducer



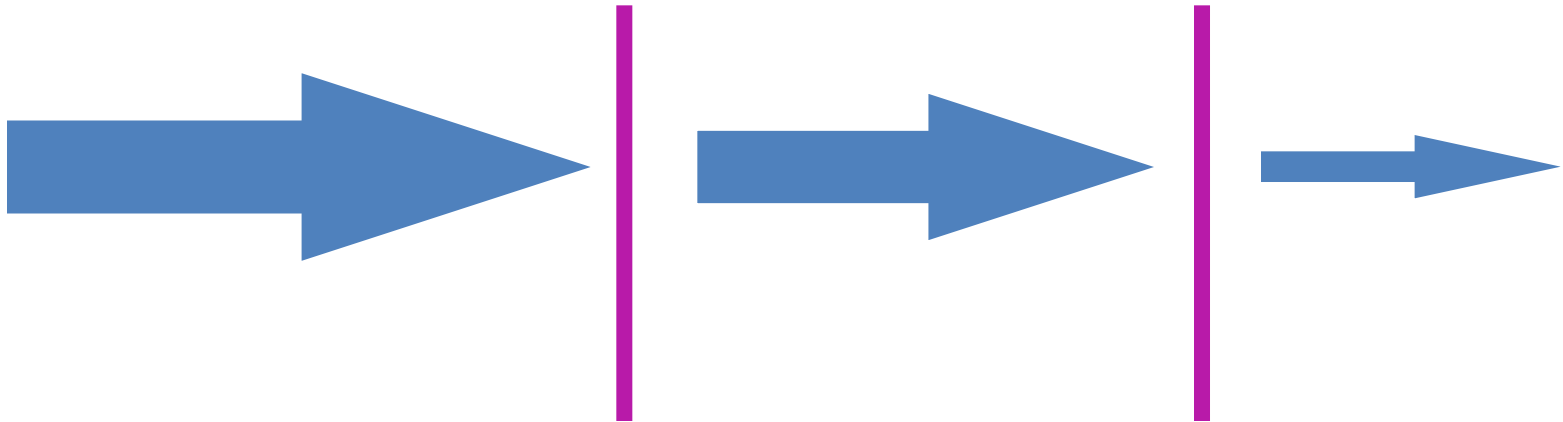
Transmission

- Not all the sound wave is reflected, some continues deeper into the body
- These waves will reflect from deeper tissue structures



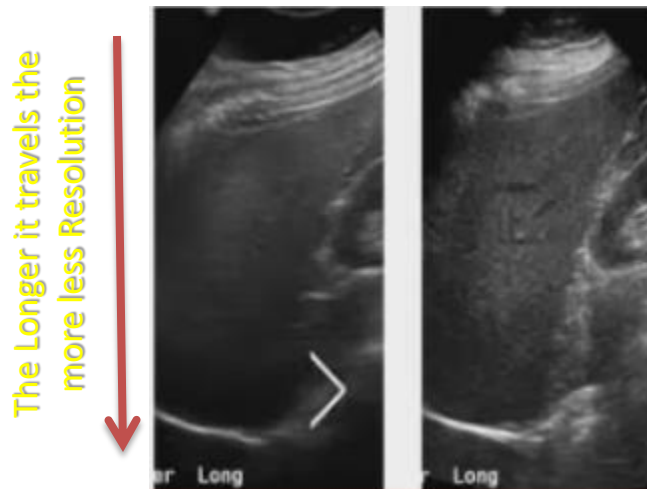
Attenuation

- The deeper the wave travels in the body, the weaker it becomes
- The amplitude of the wave decreases with increasing depth



Attenuation

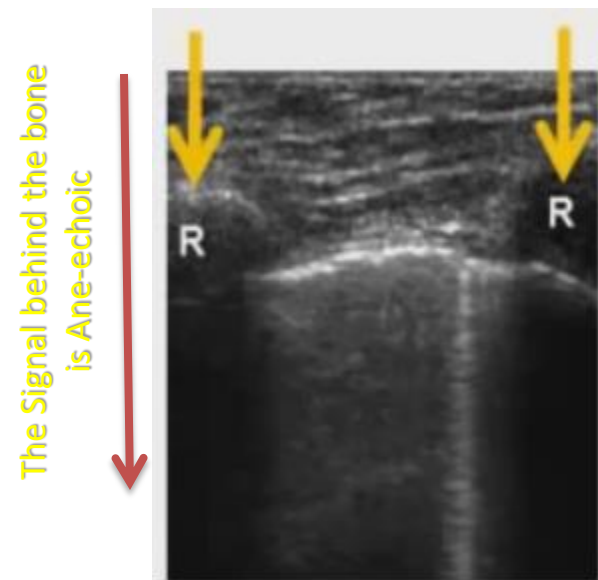
Absorption



High Freq

Low Freq

Reflection

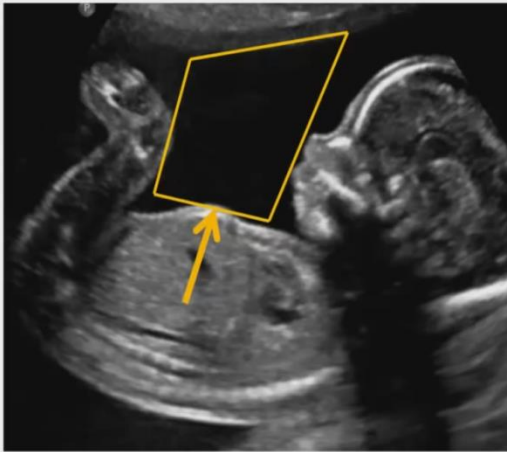


Attenuation Co-efficient

- Gas | Fluid – Low AC – allow Wave to pass
- Bones – High AC – will block

Echogenicity (caused by Reflection)

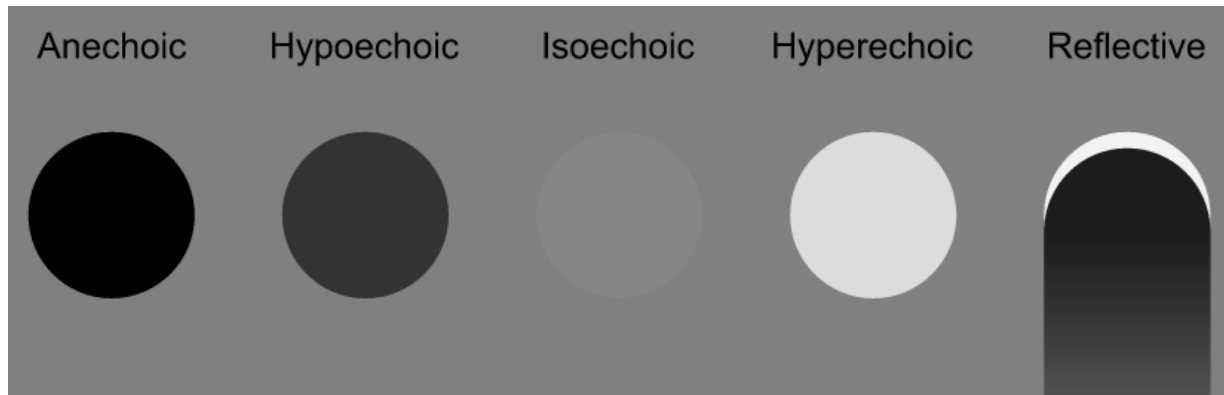
An-Echoic



Hypo-Echoic



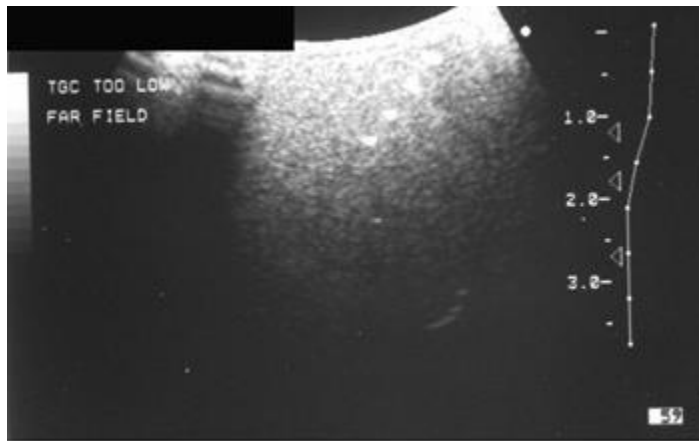
Hyper-Echoic



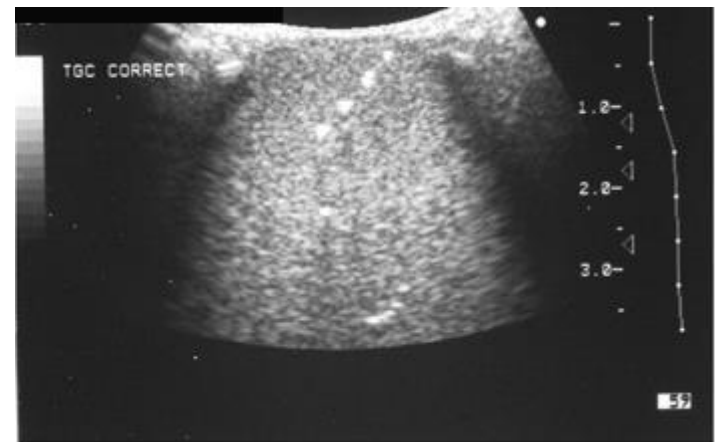
Time Gain Compensation (Post Processing)

- The Returned signal is amplified for better imaging at depths.

TGC too low far field



TGC corrected



Goal of an Ultrasound System

The ultimate goal of any ultrasound system is to make like tissues look alike and unlike tissues look different.

Accomplishing this goal depends upon...

- Acoustic Impedance
- Resolving capability of the system
 - axial/lateral resolution
 - spatial resolution
 - contrast resolution
 - temporal resolution
- Beam formation
 - send and receive
- Processing Power
 - ability to capture, preserve and display the information

Acoustic Impedance

- The product of the tissue's density and the sound velocity within the tissue
- Amplitude of returning echo is proportional to the difference in acoustic impedance between the two tissues
- Velocities:
 - Soft tissues = 1400-1600 m/sec
 - Bone = 4080 m/sec
 - Air = 330 m/sec
- Thus, when an ultrasound beam encounters two regions of very different acoustic impedances, the beam is reflected or absorbed
 - Cannot penetrate
 - Example: soft tissue – bone interface

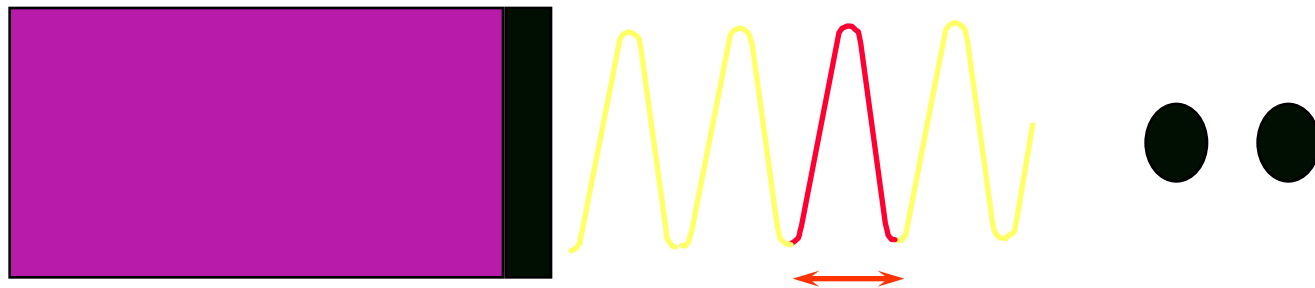
Acoustic Impedance

- Two regions of very different acoustic impedances, the beam is reflected or absorbed



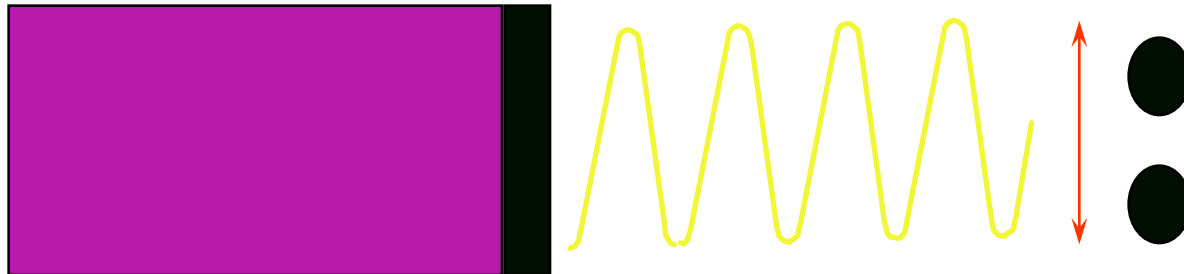
Types of Resolution

- Axial Resolution
 - specifies how close together two objects can be **along the axis** of the beam, yet still be detected as two separate objects
 - frequency (wavelength) affects axial resolution



Types of Resolution

- Lateral Resolution
 - the ability to resolve two adjacent objects that are **perpendicular** to the beam axis as separate objects
 - beam width affects lateral resolution

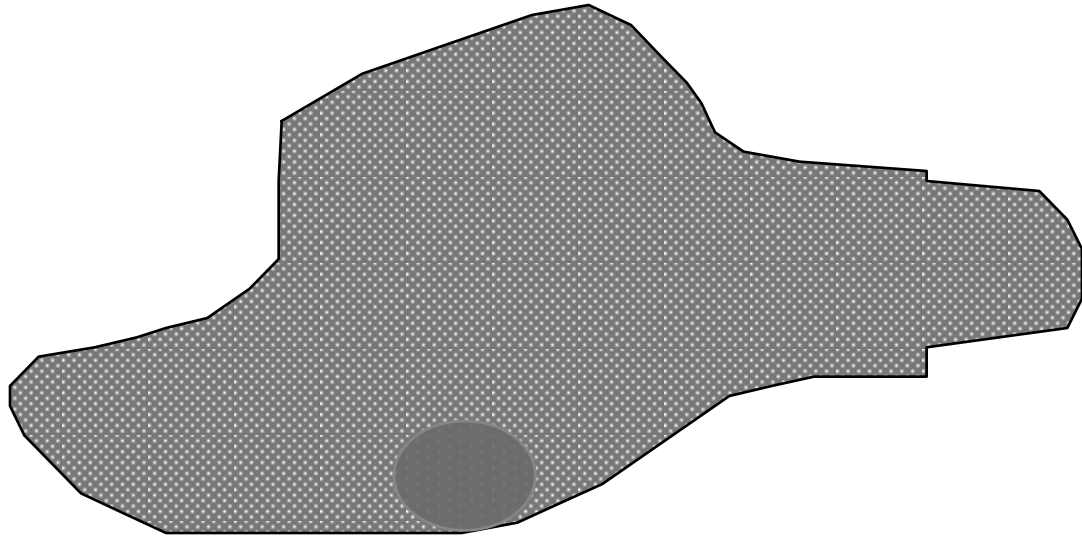


Types of Resolution

- Spatial Resolution
 - also called ***Detail*** Resolution
 - the combination of AXIAL and LATERAL resolution
 - some customers may use this term

Types of Resolution

- Contrast Resolution
 - the ability to resolve two adjacent objects of similar intensity/reflective properties as separate objects



Types of Resolution

- Temporal Resolution
 - the ability to accurately locate the position of moving structures at particular instants in time
 - also known as frame rate

What determines how far ultrasound waves can travel?

- The FREQUENCY of the transducer
 - The **HIGHER** the frequency, the **LESS** it can penetrate
 - The **LOWER** the frequency, the **DEEPER** it can penetrate
 - Attenuation is directly related to frequency
- The frequency of a transducer is labeled in Megahertz (MHz)

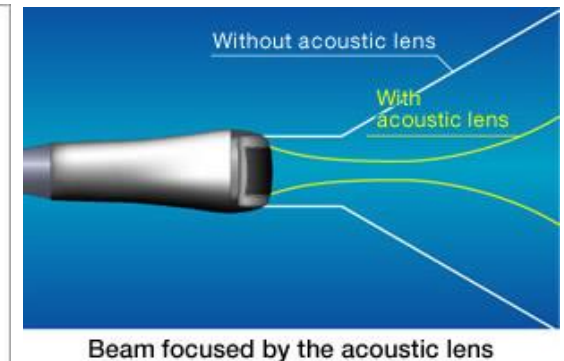
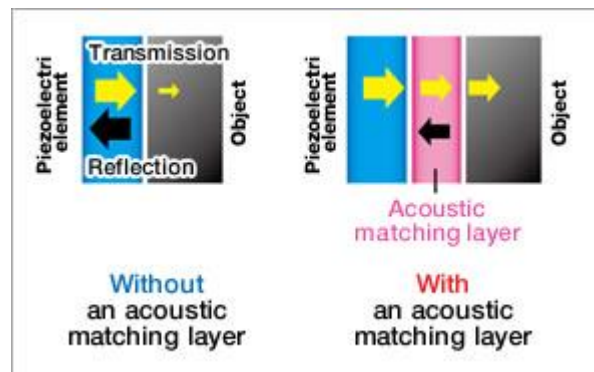
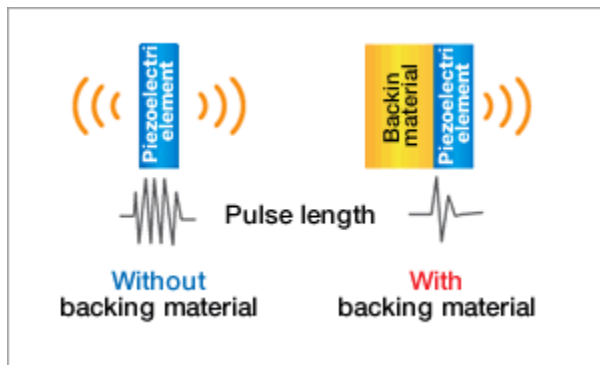
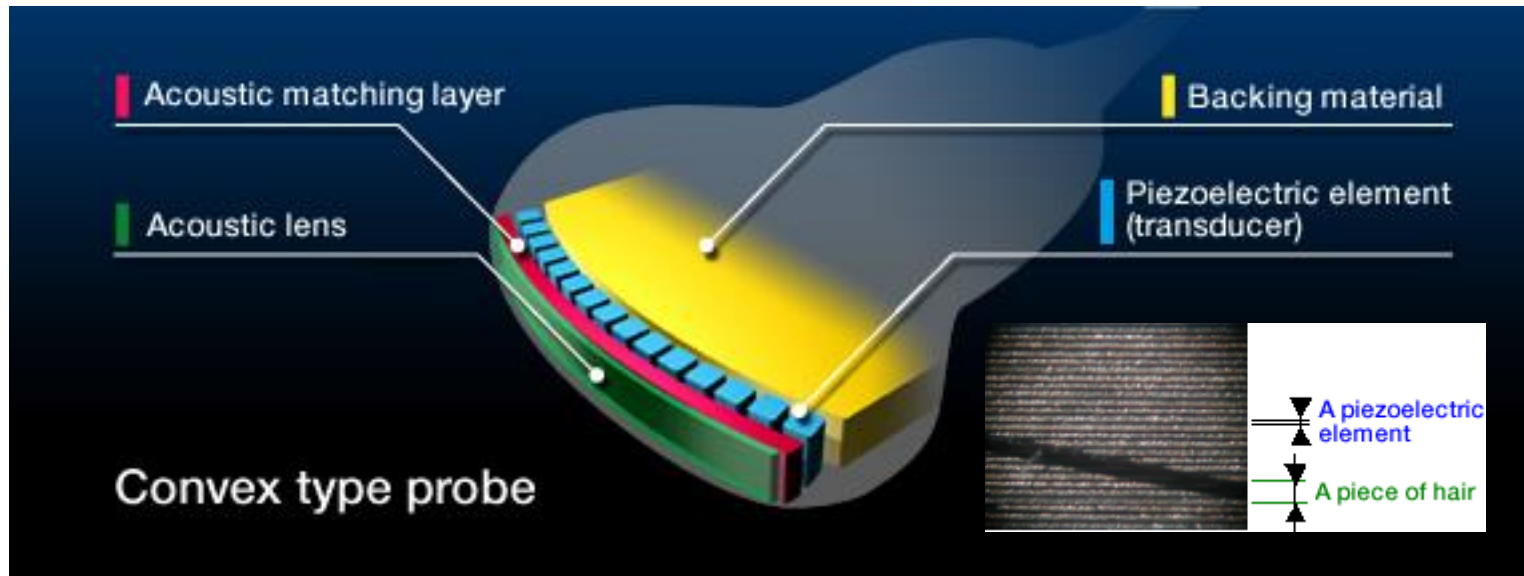
Frequency vs. Resolution

- The frequency also affects the QUALITY of the ultrasound image
 - The **HIGHER** the frequency, the **BETTER** the resolution
 - The **LOWER** the frequency, the **LESS** the resolution

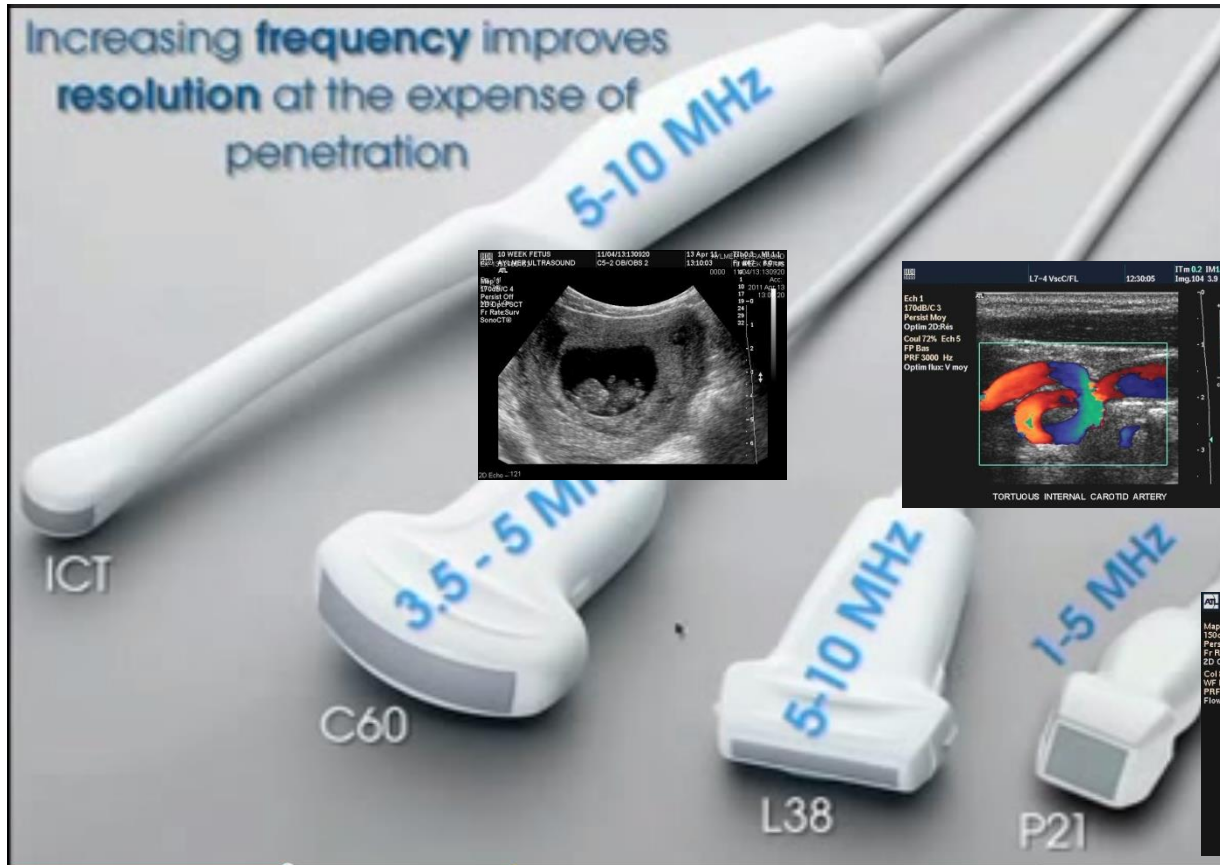
Frequency vs. Resolution

- A 12 MHz transducer has very good resolution, but cannot penetrate very deep into the body
- A 3 MHz transducer can penetrate deep into the body, but the resolution is not as good as the 12 MHz

Ultrasound - Internals



Probes

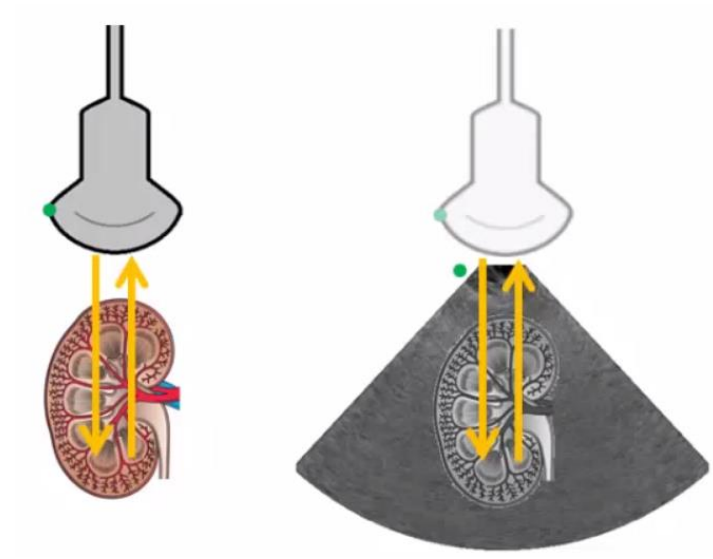
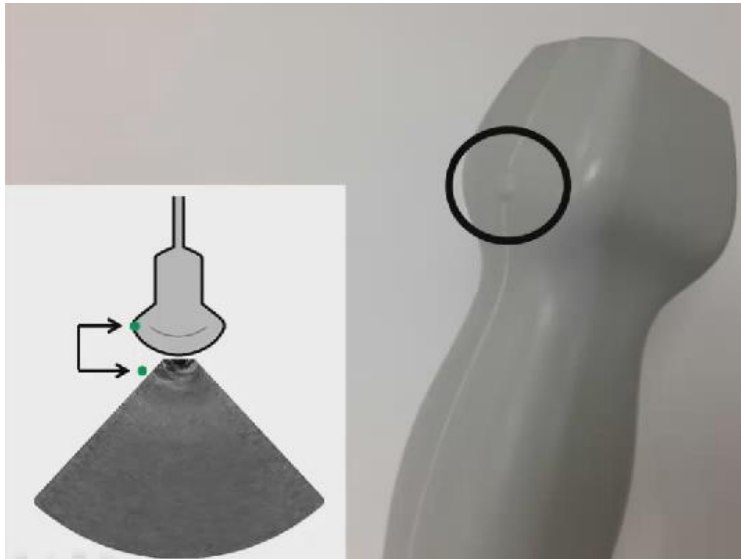


*Curvilinear
or Abdomen*

Linear or Vascular

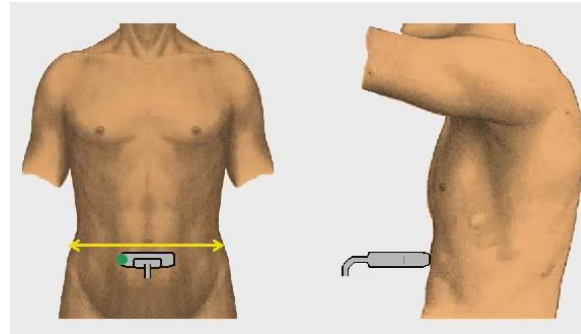
*Phased Array
or Cardiac*

Probe Orientation

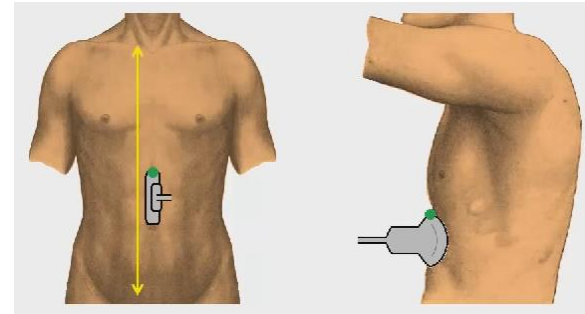


Imaging Planes

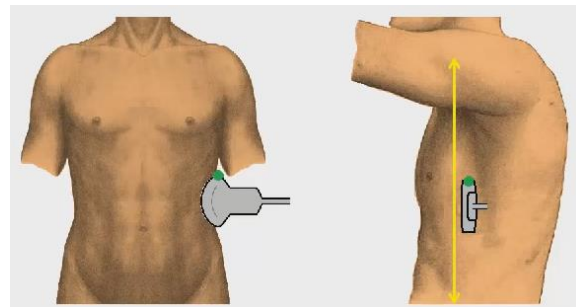
- Transverse or Axial

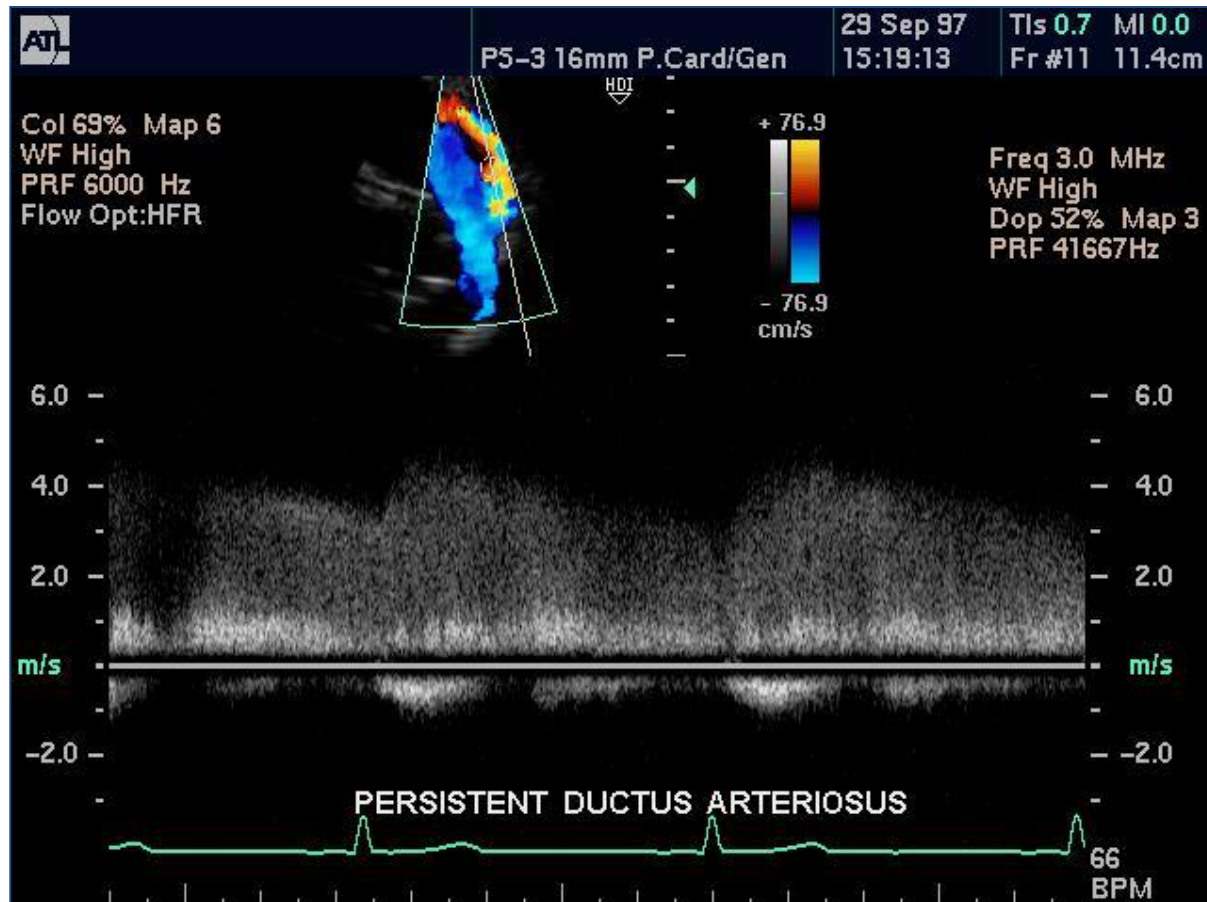


- Longitudinal or Sagittal



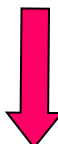
- Coronal





Basic Doppler Principles

The Doppler Effect

- Apparent change in received frequency due to a relative motion between a sound source and sound receiver
 - Sound **TOWARD** receiver = frequency 
 - Sound **AWAY** from receiver = frequency 

Doppler in Ultrasound

- Used to evaluate and quantify blood flow
 - Transducer is the sound source and receiver
 - Flow is in motion relative to the transducer
- Doppler produces an audible signal as well as a graphical representation of flow = Spectral Waveform

Doppler in Ultrasound

The Doppler shift produced by moving blood flow is calculated by the ultrasound system using the following equation:

v = Speed of Object, c = Speed of Sound in Medium

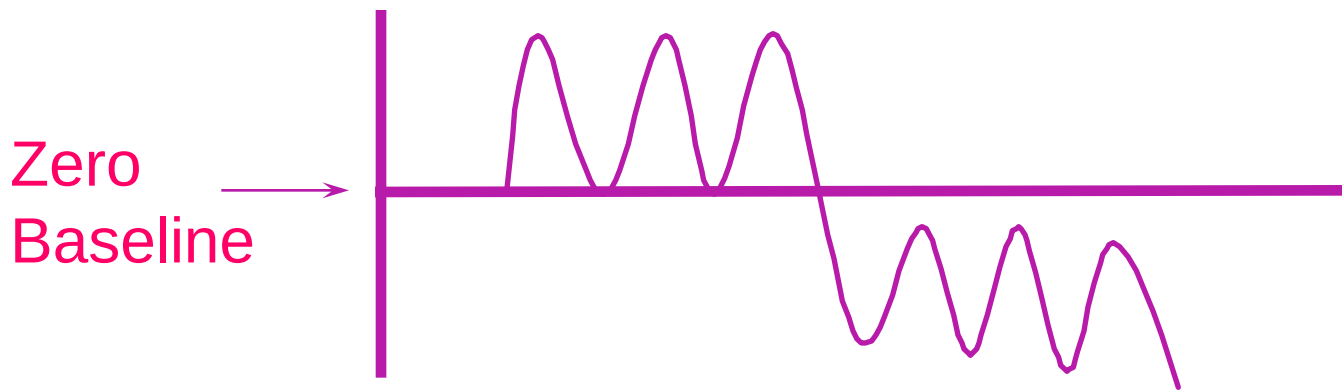
$$F_D = \frac{F_{Output} * 2 * v * \cos(\theta)}{c}$$

Doppler Display

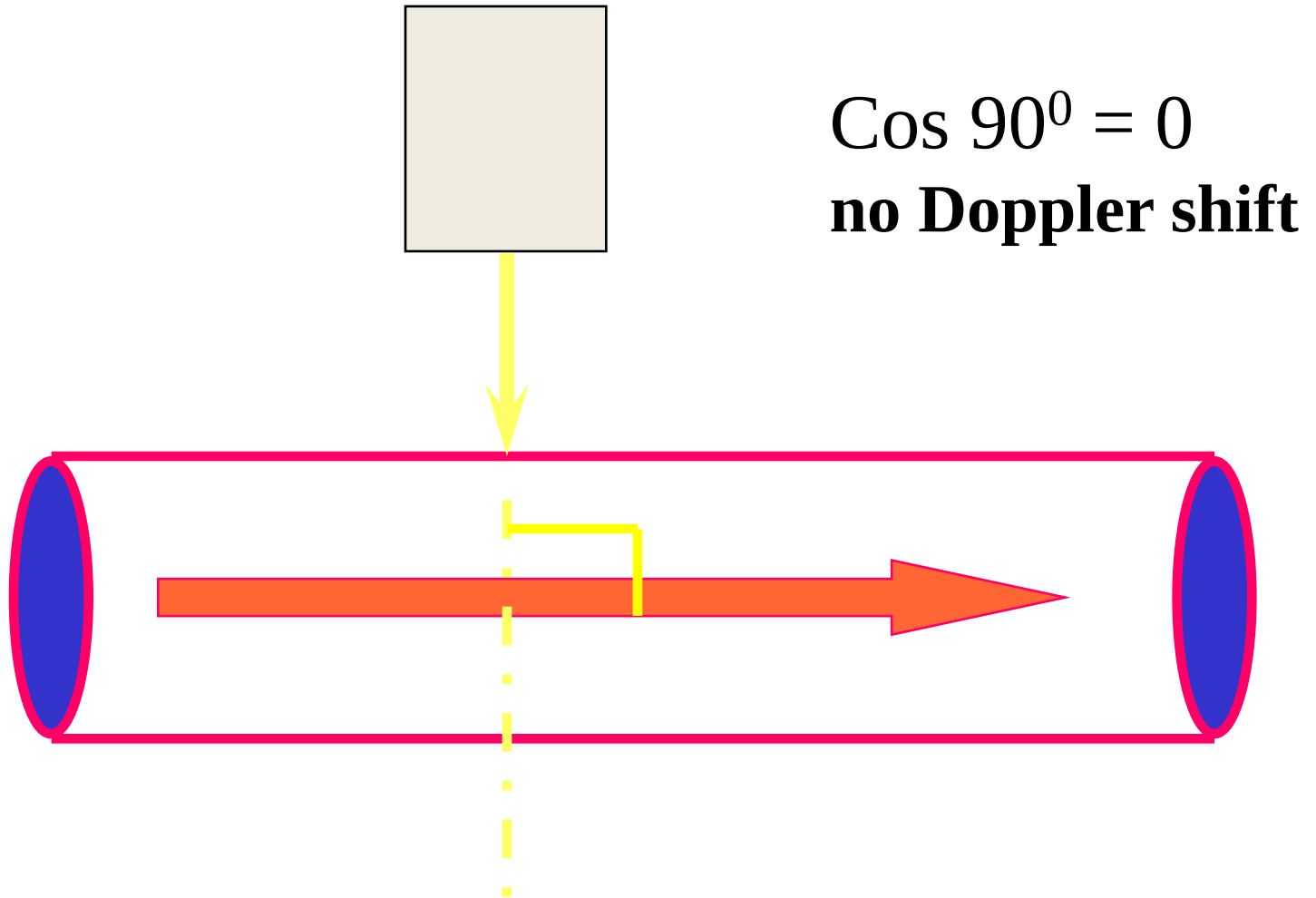
- The spectral waveform represents the audible signal and provides information about:
 - the **direction** of the flow
 - how fast the flow is traveling (**velocity**)
 - the **quality** of the flow (normal vs. abnormal)

The Direction of Flow

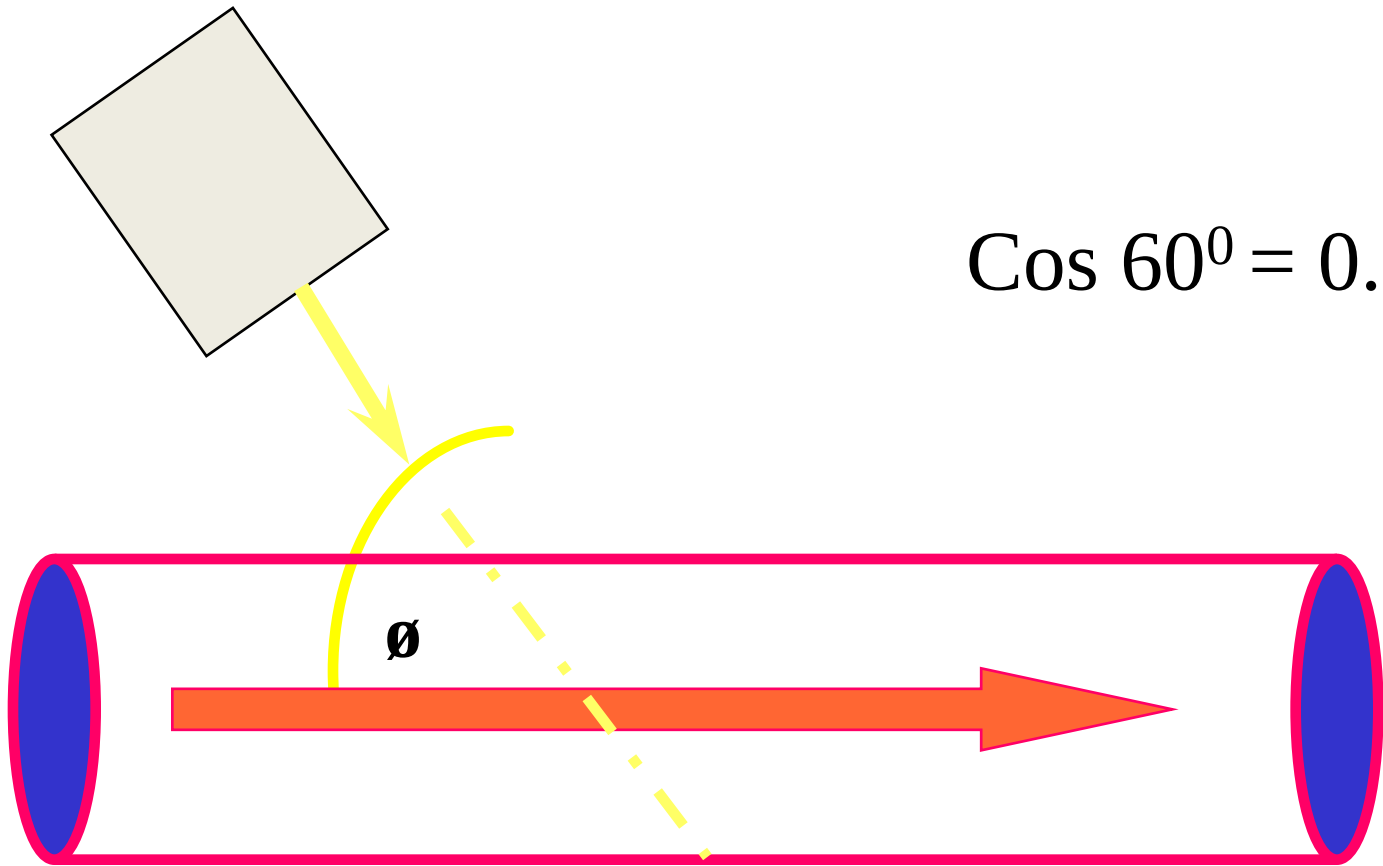
- Flow coming TOWARD the transducer is represented above the baseline
- Flow traveling AWAY from the transducer is represented below the baseline



The Direction of Flow

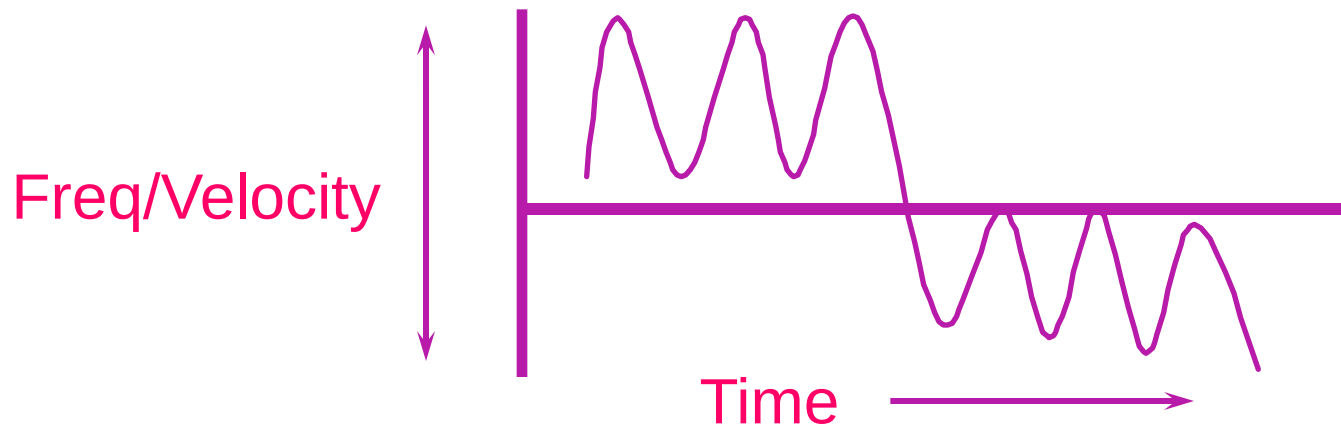


The Direction of Flow

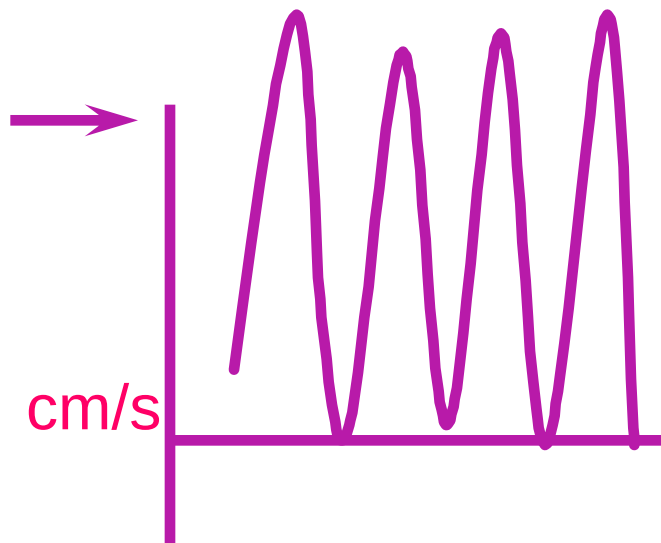


Velocity of Flow

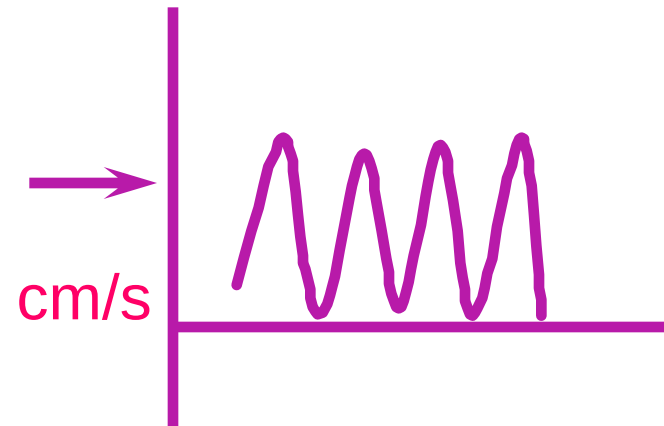
- Measuring the spectral trace provides information about velocity of flow



Velocity of Flow



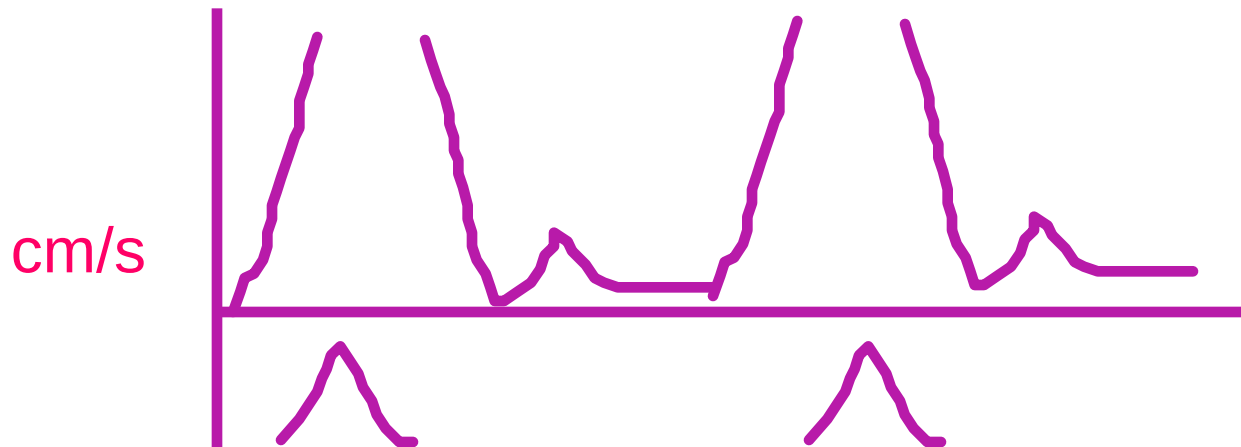
Faster Flow



Slower Flow

What if the velocity is too high to display?

- This effect is called **ALIASING (wraparound)**
- The Doppler sample rate is not adequate for high velocity shifts
- The 'peaks' are cut off and displayed below baseline



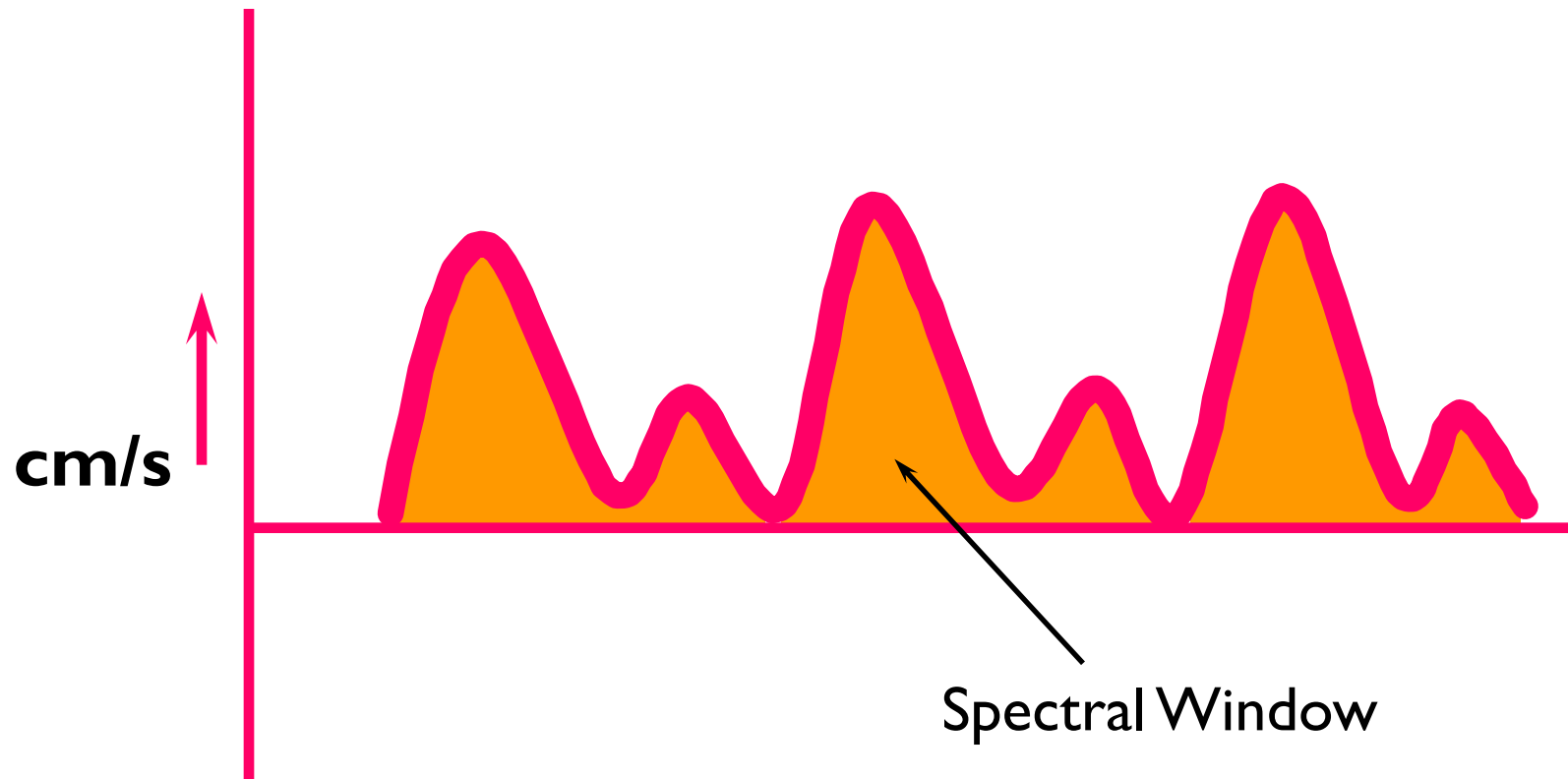
Quality of Flow

- Some examples of common measurements of the trace provide values such as:
 - Maximum and mean velocity
 - Resistance Index (RI)
 - Pulsatility Index (PI)
 - Acceleration and Deceleration Times
 - Volume flows, shunts, pressure gradients

Spectral Analysis

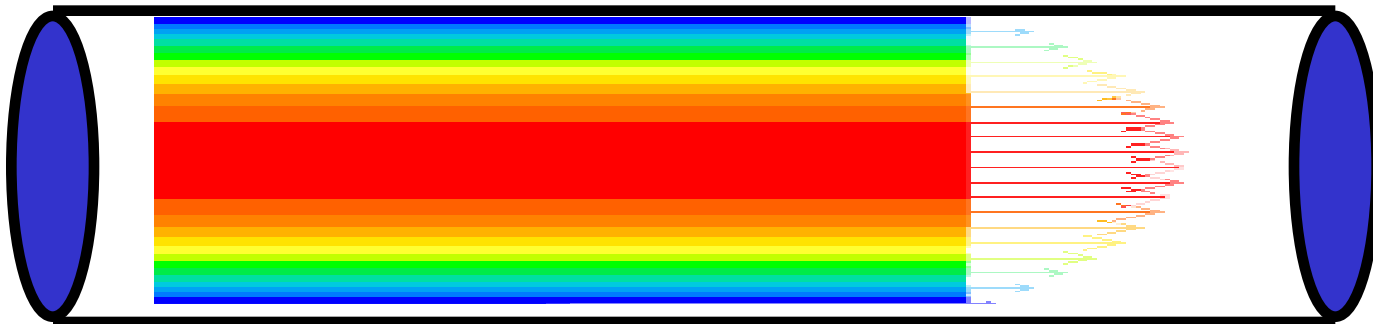
- Each of these measurements has a normal range of values for specific clinical applications
- The amount of disease present is based on these calculated values
- Also, the ENVELOPE or WINDOW provides information about the quality of flow

Spectral Analysis



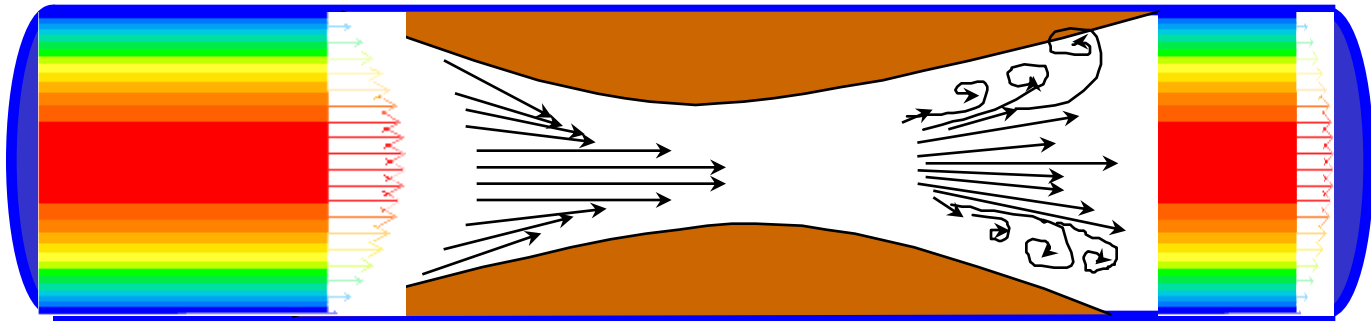
Laminar Flow

- Layers of flow (normal)
- Slowest at vessel wall
- Fastest within center of vessel



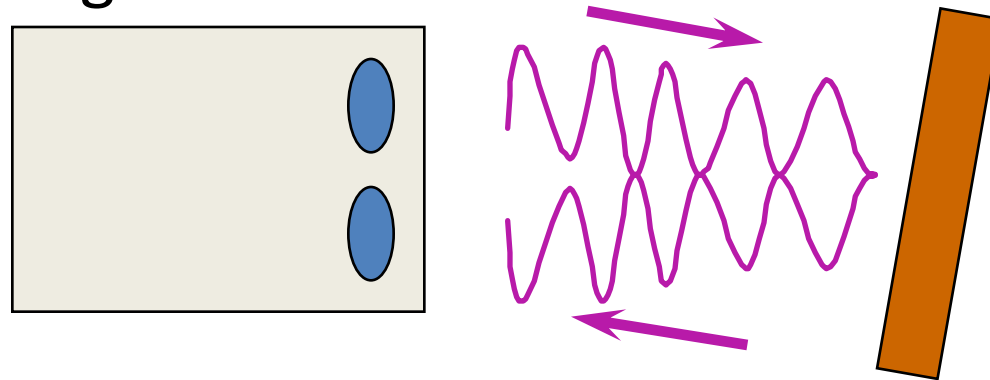
Laminar Flow

- Disease states disrupt laminar flow



Types of Doppler

- Continuous Wave (CW)
 - Uses **different** crystals to send and receive the signal
 - One crystal **constantly** sends a sound wave of a single frequency, the other **constantly** receives the reflected signal

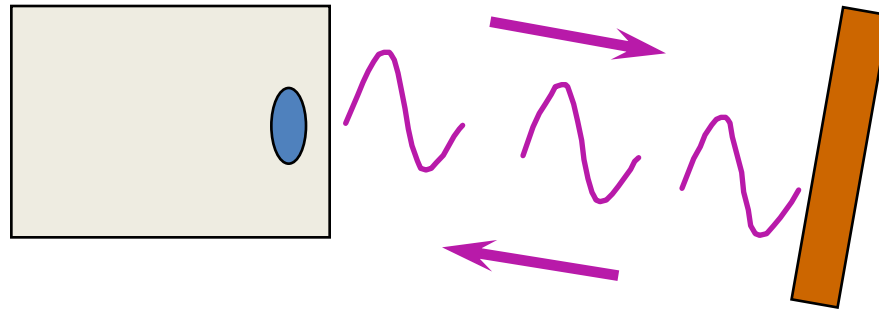


Types of Doppler

- Advantages of CW
 - Can accurately display flow of any velocity **without aliasing**
- Disadvantages of CW
 - Samples everything along the Doppler line
 - Cannot position the Doppler to listen at a specific area along it's path

Types of Doppler

- Pulsed Wave (PW)
 - Produces short bursts/pulses of sound
 - Uses **the same** crystals to send and receive the signal
 - This follows the same pulse-echo technique used in 2D image formation



Types of Doppler

- Advantages of PW
 - Can sample at a specific site along the Doppler line. The location of the sample is represented by the Sample Volume
- Disadvantages of PW
 - The maximum velocity which can be displayed is limited. The signal will always **alias** at a given point, based on the transducer frequency.

Types of Doppler

- Continuous Wave is widely used in Cardiology Applications
 - Requires ability to display very high velocities without aliasing
- Pulsed Wave is used in all clinical applications.

What defines a good Doppler display?

- No background noise
- Clean window/envelope in normal flow states
- Clear audible signal
- Accurate display of velocities

Clinical Challenges with Doppler

- Obtaining the appropriate Doppler angle
- Doppler in deep vessels/large patients
- Displaying without aliasing, found in abnormal flow states (PW Doppler)
- Exact site for sampling



Color Doppler Imaging

Why use Color?

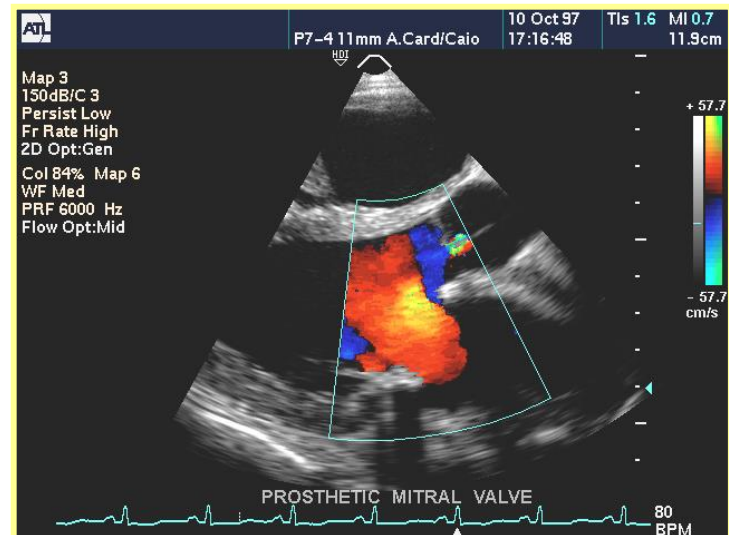
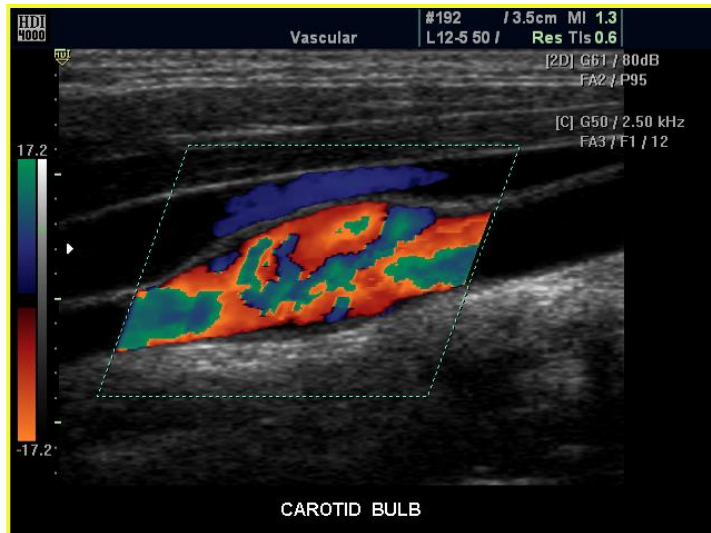
- To visualize blood flow and differentiate it from surrounding tissue
- Provides a 'map' for placing a Doppler sample volume
- The basic questions are
 - Is there flow present?
 - What direction is it traveling?
 - How fast is it traveling?

What is Color Doppler?

- Utilizes pulse-echo Doppler flow principles to generate a color image
- This image is superimposed on the 2D image
- The red and blue display provides information regarding DIRECTION and VELOCITY of flow

Direction of Flow with Color

- Linear array transducers display a square shaped color box which STEERS from left to right to provide a Doppler angle
- All other transducers display a sector shaped color box which is adjusted in position by using the trackball

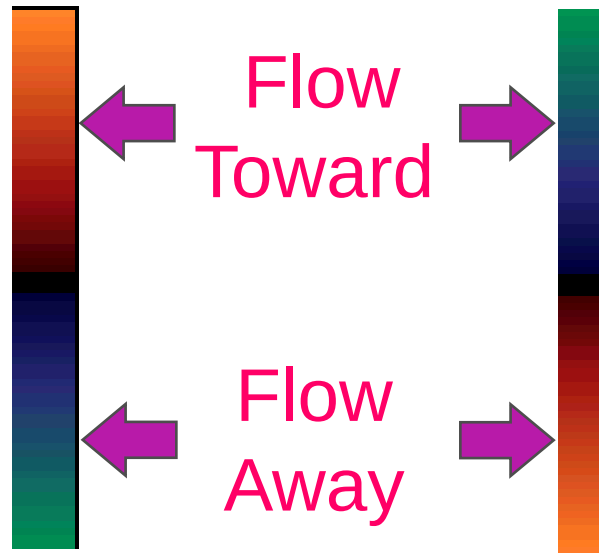


Region of interest

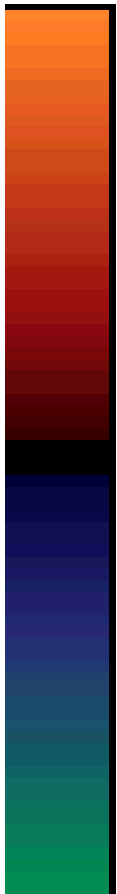
- Position:
 - The box must approach the vessel/heart chamber at an angle **other** than 90 degrees
 - Following the Doppler principle, there will be little or no color displayed at perpendicular incidence
- Size
 - The larger the ROI the lower the frame rate

Direction of Flow with Color

- Regardless of color, the top of the bar represents flow coming towards the transducer and the bottom of the bar represents flow away from the transducer



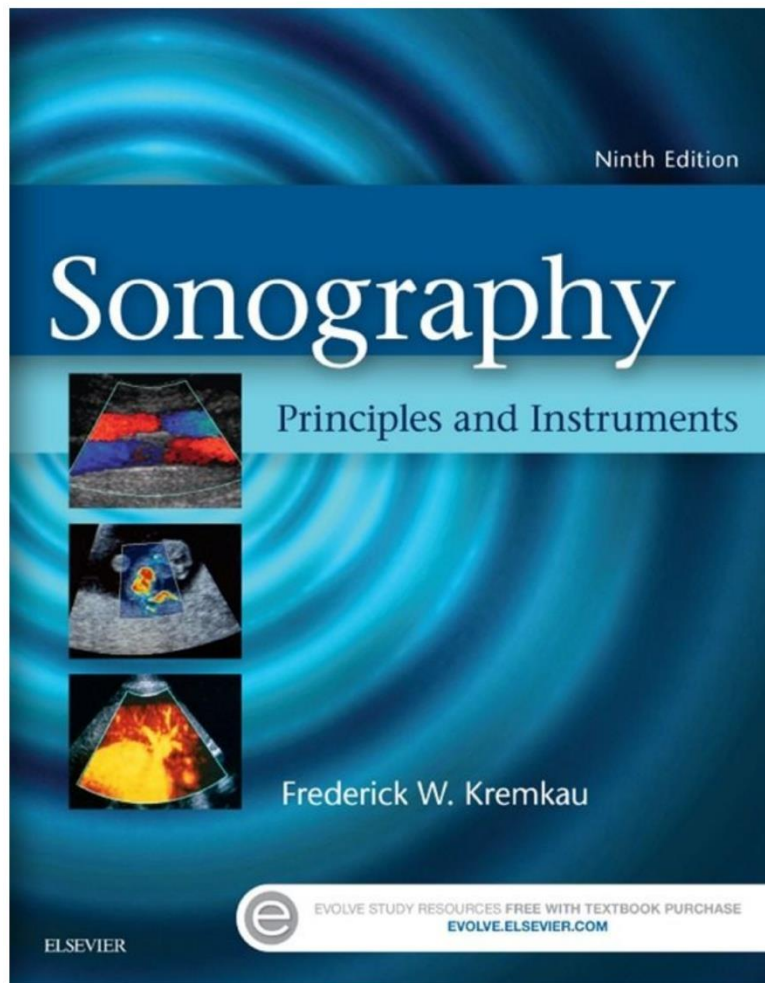
Velocity of Flow with Color

- 
- The SHADING of the color provides information about the VELOCITY of the flow
 - The DEEPER the shade of red or blue, the slower the flow
 - The LIGHTER the shade, the faster the flow

The End

M-Mode
3D-Ultrasound
Contrasting Agents

Based on:



PHILIPS

Physics of Ultrasound

Karen Lamble
Jennifer Green
European Training Managers