chapter 1

Ultrasound Physics

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Definitions

Sound A type of wave that carries energy from place to place.

- Created by the vibration of a moving object.
- Sound waves are comprised of compressions (increases in pressure or density ψ) and rarefactions (decreases in pressure or density ψ).
- Sound cannot travel through a vacuum—sound must travel through a medium. ψ
- Sound is a **mechanical, longitudinal** wave.
- Sound travels in a straight line.

Acoustic Variables

Acoustic variables specifically **identify** sound waves. When an acoustic variable changes rhythmically in time, a sound wave is present.

Pressure Concentration of force within an area. *Units:* Pascals (Pa)

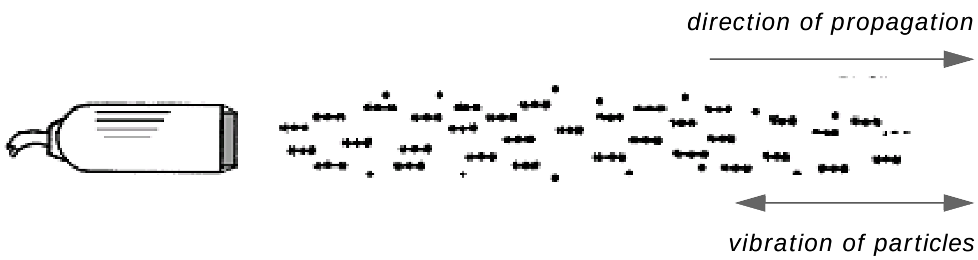
Density Concentration of mass within a volume. *Units:* kg/cm^3

Distance Measure of particle motion. *Units:* cm, feet, miles

Waves

Transverse Wave ψ Particles move in a direction perpendicular (at right angles) to the direction of the wave:

Longitudinal Wave ψ Particles move in the *same direction* as the wave:



Compressions are regions of higher density & pressure

Rarefactions are regions of lower density & pressure

Seven parameters that describe sound waves:

Period
Frequency

Amplitude
Power
Intensity

Speed

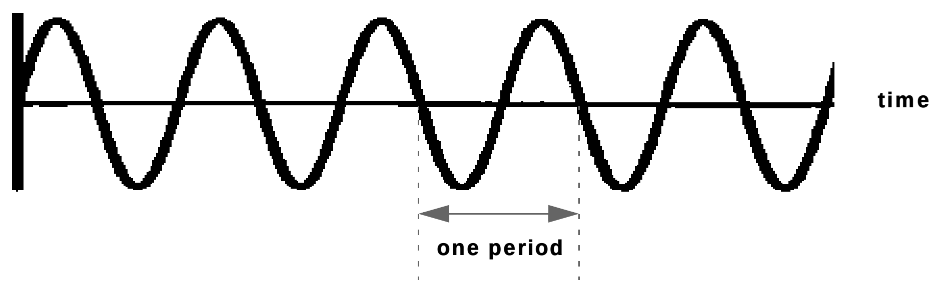
Wavelength

Note **Acoustic variables** identify sound waves

Acoustic parameters describe the particular features of sound waves

Period

Definition	The time required to complete a single cycle.
	Period can also be described as the time from the start of a cycle to the start of the next cycle.
Example	The period of the moon circling the earth is 28 days.
	The period of class in high school may be 50 minutes.
Units	μsec, seconds, hours—all units of time
Typical Values	0.1 to 0.5μsec
	0.0000001 to 0.0000005sec
	1×10^{-7} to 5×10^{-7}sec
Determined By	Sound source
Changed by Sonographer	No



Frequency

Definition	The number of *certain events* that occur in a particular time duration.
	In diagnostic ultrasound, the frequency of a wave is described as the number of cycles of an acoustic variable that occur in one second.
Units	per second, $\frac{1}{\text{second}}$, Hertz, Hz
Determined By	Sound source
Changed by Sonographer	No

Ultrasound A wave with a frequency exceeding 20,000 Hz. This frequency is so high that it is not audible.

Audible Sound Heard by man, a frequency between 20 Hz and 20,000 Hz.

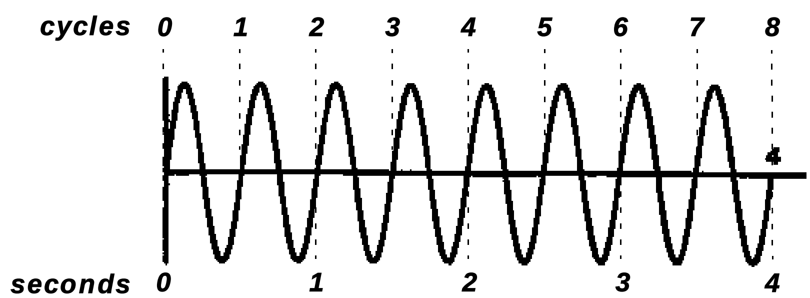
Infrasound A frequency less than 20 Hz. This frequency is so low that it is not audible.

Typical Values Range from 2 MHz to 10 MHz

Note Frequency is inversely related to penetration.

Frequency is related to axial resolution, higher frequency improves image quality.

Example



There are 8 cycles that occur in 4 seconds; the frequency of this wave is $\frac{8}{4}$ or 2 Hz.

Frequency and Period

Related, period and frequency are **reciprocals**.

This is also called an **inverse relationship** (when one goes up, the other down).

In reality, frequency is derived from period.

> As frequency *increases*, period *decreases*.
>
> As frequency *decreases*, period *increases*.
>
> If period is *unchanged*, frequency is also *unchanged*.

Equation

$$\text{frequency (Hz)} \times \text{period (sec)} = 1$$

$$\text{period (sec)} = \frac{1}{\text{frequency (Hz)}}$$

$$\text{frequency (Hz)} = \frac{1}{\text{period (sec)}}$$

Remember to use complementary units:

» sec & Hz

» msec & kHz

concerned with the strength of a sound beam.

Definition The difference between the average value and the maximum value of an acoustic variable. The variation of an acoustic variable.

Units Those of the acoustic variables: ψ

Pressure–Pascals

Density–grams/cubic cm

Particle motion–cm, inches, units of distance

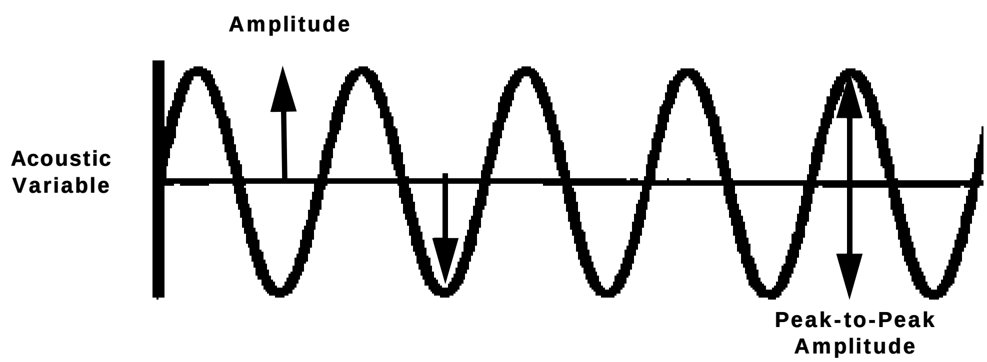
Amplitude can also be expressed in ***decibels*****, dB.** ψ

Determined By Sound source (initially)

Changed by Sonographer Yes

Amplitude decreases as sound propagates through the body.

The difference between maximum and minimum values of an acoustic variable is called the *peak-to-peak amplitude*. Amplitude is half of the peak-to-peak amplitude.



Power

Definition The rate that work is performed, or the rate of energy transfer.

Units for **power**:
think of a light bulb or stereo!

Units Watts! ψ

Determined By Sound source (initially)

Changed by Sonographer Yes

Power decreases as sound propagates through the body.

Intensity

Definition The concentration of energy in a sound beam.

The beam’s power divided by the beam's cross sectional area.

Intensity depends upon both the power and the cross sectional area of the beam:

Equation ψ

$$\text{intensity}\left(\frac{\text{watts}}{\text{cm}^2}\right) = \frac{\text{power (watts)}}{\text{beam area (cm}^2\text{)}}$$

Units watts/square cm or watts/cm^2 (watts from power, and cm^2 from beam area.)

Determined By Sound source (initially)

Changed by Sonographer Yes

Intensity decreases as sound propagates through the body.

Intensity is the key parameter for bioeffects & safety.

Wavelength

Definition The length or distance of a single cycle.

Similar to the length of a single boxcar in a train of infinite length.

Units mm or any unit of **length**

Determined By **Both** the source and the medium

Changed by Sonographer No

Wavelength influences axial resolution (image quality).

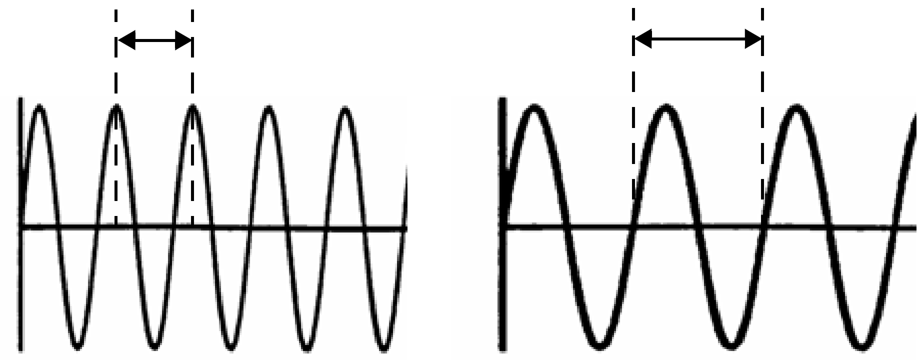
Typical Values 0.1–0.8 mm

Equation

$$\text{wavelength (mm)} = \frac{\text{propagation speed (mm/}\mu\text{s)}}{\text{frequency (MHz)}}$$

Higher frequency also means shorter wavelength

Lower frequency also means longer wavelength.



Wavelengths in Soft Tissue

- In soft tissue, sound with a frequency of 1 MHz has a wavelength of 1.54 mm.

Rule

In soft tissue, divide 1.54 mm by the frequency in MHz.

Wavelength (mm) = 1.54 / frequency (MHz)

Propagation Speed

Definition The rate that sound travels through a medium.

Units meters per second, mm/µs

Determined By *Medium* only

Density and stiffness

Changed by Sonographer No

Typical Values

- Average speed of all sound (regardless of frequency) in *biologic* or "*soft tissue*:"
- 1.54 km/s = 1,540 m/s = 1.54 mm/µs
-

Medium	Speed (m/s)
Air	330
Lung	300 - 1,200
Fat	1,450
Soft Tissue	1,540
Bone	2,000–4,000

Rule of Thumbs

> **Density** is related to weight
>
> **Stiffness** is related to 'squishability'

Density and **S**peed — opposite directions ψ

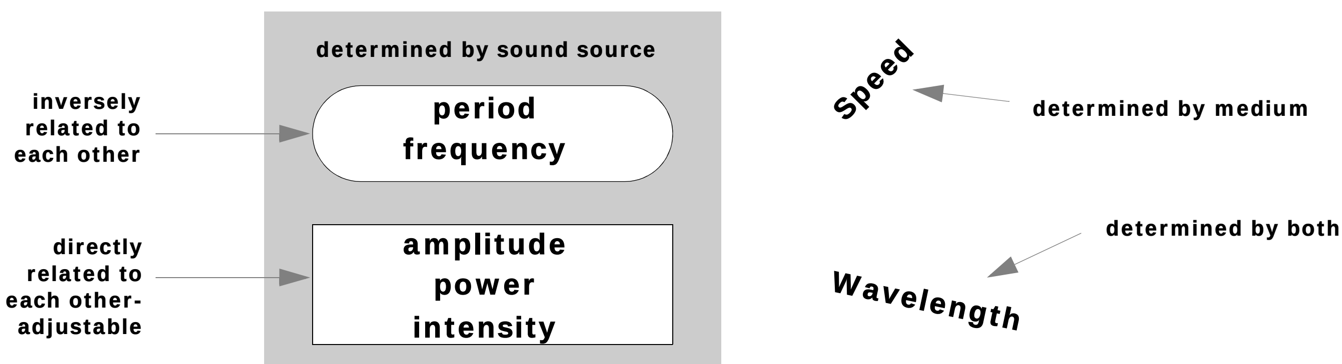
Stiffness and **S**peed — same direction ψ

» ***General Rule:*** *gas (slower) < liquid < solid (faster)*

Note: All sound, regardless of the frequency, travels at the same speed through any specific medium. This means that sound with a frequency of 5MHz and sound with a frequency of 3MHz travel at the same propagation speed if they are traveling through the same medium.

Equation speed $\left(\frac{m}{s}\right)$ = frequency (Hz) x wavelength (meters)

The Skinny



chapter 2

Pulsed Ultrasound

Basic Rule

the pulse doesn't change

the listening time changes when depth of view is altered

Pulse Duration

Definition The time from the **start** of a pulse to the **end** of that pulse, only the **actual time** that the pulse is "on".

Units μsec—all units of time

Determined By Sound source

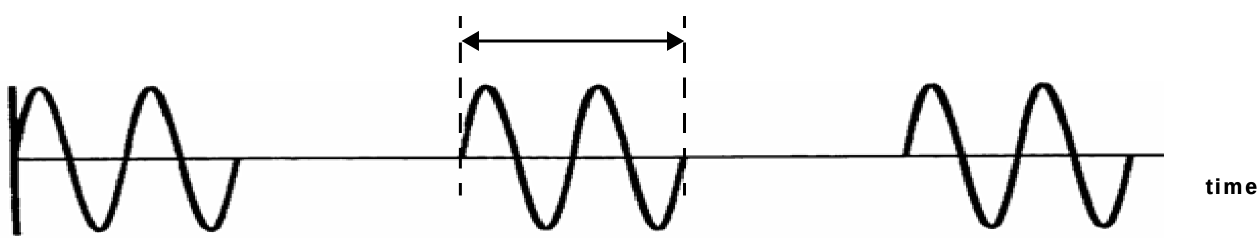
Pulse duration is determined by the **number of cycles** in each pulse and the **period** of each cycle.

Changed by Sonographer No, *does not* change when sonographer alters imaging depth.

Pulse duration is a characteristic of each transducer.

Typical Values In clinical imaging, pulse duration ranges from 0.5 to 3μsecs.

In clinical imaging, a pulse is comprised of 2–4 cycles.



Equation

$$\text{Pulse Duration (msec)} = \text{\# cycles in pulse} \times \text{period (msec)}$$

$$\text{Pulse Duration (msec)} = \frac{\text{\# cycles in pulse}}{\text{frequency (kHz)}}$$

Pulse Repetition Period

Definition Pulse repetition period is the time from the *start* of one pulse to the *start* of the next pulse. It includes both the time that the pulse is "on" and the "dead time."

Units msec—all units of time

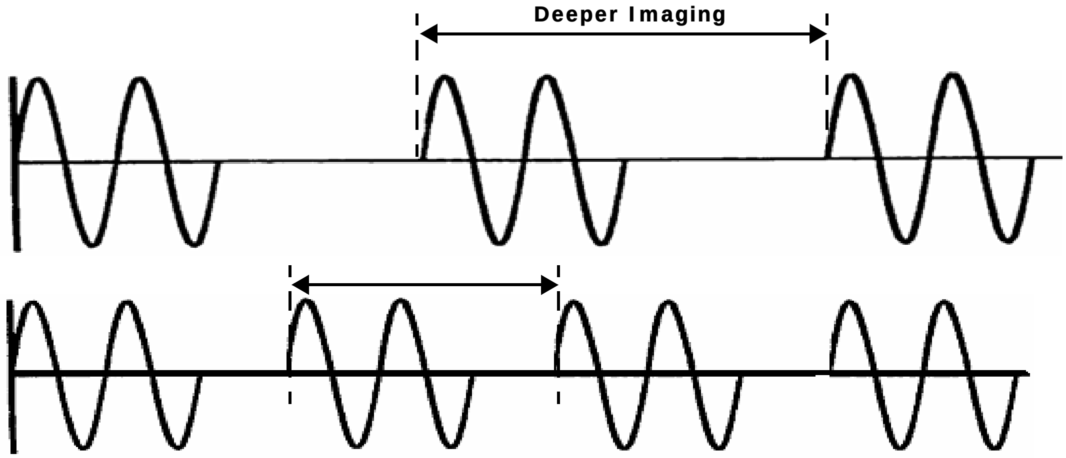
Determined By Sound source

Changed by Sonographer Yes

The operator changes only the "listening time" (when adjusting the depth of view), never the pulse duration.

Typical Values In clinical imaging, the PR period has values from 100 μsec to 1 msec.

Equation PRP = 13 μs/cm X depth of view (cm)



Pulse Repetition Frequency

Definition **PRF** is the number of **pulses** that occur in one second.

HINT: PRF is only related to depth of view, it is not related to frequency.

Units Hertz, hz, per second

Determined By Sound source

Changed by Sonographer Yes

Typical values In clinical imaging, from 1,000–10,000Hz (1-10kHz) ψ

Notes

- The PRF depends upon imaging depth.

Equation

- **PRF (hz)= 77,000 (cm/s) / depth of view (cm)**
- As imaging depth increases, PRF decreases (inverse relationship).
- In most cases, only one pulse of US travels in the body at one time. Thus, as imaging depths changes, PRF changes.

Since the operator determines the maximum imaging depth, the operator alters the PRF.

Thus, the operator also adjusts the pulse repetition period.

Shallow image, higher PRF.
Deeper image, lower PRF.

Relationship

- **Pulse repetition period** and **pulse repetition frequency** are **reciprocals** (inverse relationship-when one parameter goes up, the other goes down). Therefore, pulse repetition period also depends upon imaging depth.

Equation

$$\text{pulse repetition period X PRF frequency} = 1$$

Duty Factor

Definition The percentage or fraction of time that the system transmits a pulse. Important when discussing intensities.

Units

» Maximum = 1.0 or 100% **Unitless!**

» Minimum = 0.0 or 0%

If the duty factor is 100% or 1.0, then the system is always producing sound. It is a continuous wave machine.

If the duty factor is 0%, then the machine is never producing a pulse. It is off.

Determined By Sound source

Changed by Sonographer Yes

Typical values **From 0.001 to 0.01 (little talking, lots of listening)**

As we know, the operator adjusts the maximum imaging depth and thereby determines the pulse repetition period. Therefore, the operator indirectly changes the duty factor while adjusting imaging depth.

Note CW sound cannot be used to make anatomical images.

If an ultrasound system is used for imaging, it must use pulsed ultrasound and, therefore, the duty factor must be **between** 0% and 100% (or 0 and 1), typically close to 0.

Equation

$$\text{duty factor (\%)} = \frac{\text{pulse duration (msec)}}{\text{pulse repetition period (msec)}} \times 100$$

Spatial Pulse Length

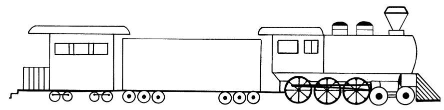
Definition The length or distance that a pulse occupies in space. The distance from the start of a pulse to the end of that pulse.

Units mm, meters—any and all units of distance

Determined By **Both** the source and the medium

Changed by Sonographer No

Example For SPL, think of a train (the pulse), made up of cars (individual cycles). The overall length of our imaginary train from the front of the locomotive to the end of the caboose.



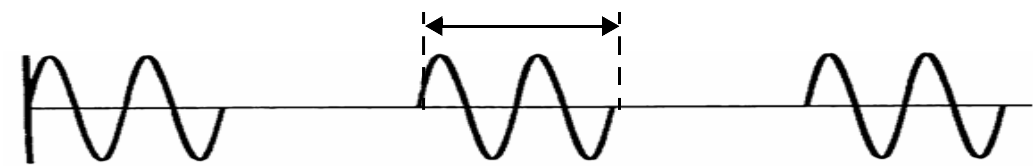
Typical Values 0.1 to 1 mm.

Note Important - it determines axial resolution (image quality).

Shorter pulses create higher quality images.

Equation Spatial Pulse Length (mm) = # of cycles × wavelength (mm)

Hint If we know the length of each boxcar in the train and we know the number of cars in the train, then we know the total length of the train!



Parameters of Pulsed Waves

Parameters	Basic Units	Units	Determined By	Typical Values
pulse duration	time	sec, μsec	sound source	0.5 – 3.0 μsec
pulse repetition period	time	sec, msec	sound source	0.1 – 1.0 msec
pulse repetition frequency	1/time	1/sec, Hz	sound source	1 – 10 kHz
spatial pulse length	distance	mm, cm	source & medium	0.1 – 1.0 mm
duty factor	none	none	Sound Source	0.001 – 0.01

By adjusting the imaging depth, the operator changes the ***pulse repetition period***, ***pulse repetition frequency***, and ***duty factor***.

The ***pulse duration*** and ***spatial pulse length*** are characteristics of the pulse itself and are inherent in the design of the transducer system. They are not changed by sonographer.

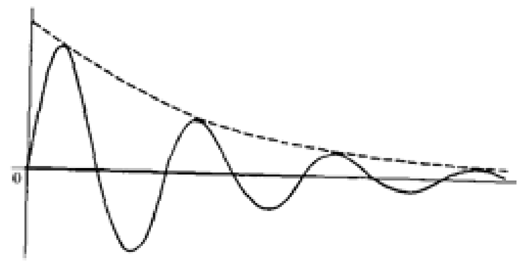
chapter 3

Interaction of Sound and Media

Attenuation

Definition The decrease in intensity, power and amplitude of a sound wave as it travels.

The farther US travels, the more attenuation occurs.



Units dB, decibels ψ (must be negative, since the attenuation causes intensity to decrease)

In soft tissue Attenuation of sound in soft tissue is

1) directly related to **distance** traveled**,** and
2) directly related to **frequency.** This is why we are able image deeper with lower frequency ultrasound.

Three Components

1. Absorption (sound energy converted into heat energy)
2. Scattering
3. Reflection

Media

- **Air**—much, much more attenuation than in soft tissue
- **Bone**—more than soft tissue, absorption & reflection
- **Lung**—more than soft tissue, due to scattering
- **Water**—much, much less than soft tissue

Air >> Bone & Lung > Soft Tissue >> Water

Note Attenuation of sound in **blood** is approximately equal to that in soft tissue.

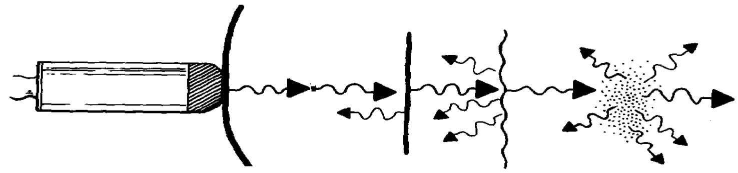
Hint Attenuation and speed are totally unrelated.

Overall attenuation is increased when:

1) frequency increases or

2) path length increases

Reflection and Scattering



Reflection

Occurs when propagating sound energy strikes a boundary between two media and some returns to the transducer.

Specular Reflection

Reflections from a very smooth reflector (mirror) are specular

Specular reflections also occur when the wavelength is much smaller than the irregularities in the boundary. ψ

Note

Specular reflectors are well seen when sound strikes the reflector at 90°. Specular reflectors aren't well seen when the wave strikes the reflector at angles other than 90°.

Diffuse (Backscatter) Reflection

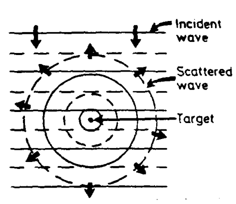
Sound returning towards the transducer that is disorganized and random.

Occurs when the boundary has irregularities that are approximately the same size as the sound's wavelength.

Scattering

If the boundary between two media has irregularities (with a size **similar to** or **a bit smaller than** the pulse's wavelength), then the wave may be chaotically redirected in all directions.

Rayleigh Scattering



If a reflector is **much smaller** than the wavelength of sound, the sound is uniformly diverted in all directions. Higher frequency sound undergoes more Rayleigh scattering. A red blood cell is a Rayleigh scatterer.

Rayleigh scattering is proportional to frequency ^{4}

Attenuation & Imaging Depth

Attenuation ultimately limits the maximum depth from which images are obtained. The goal in diagnostic imaging is to use the highest frequency that still allows us to image to the depth of the structures of clinical interest. That is why we use 2–10 Mhz sound waves.

	Organized systematic	**Disorganized** chaotic
Reflection (back to transducer)	Specular	Diffuse or Backscatter
Scattering (in all directions)	Rayleigh	Scatter

Impedance

Characteristic of the *medium* only.

Impedance is not measured, *it is calculated*.

Units Rayls, often represented by the letter "Z".

Typical Values Between 1,250,000 and 1,750,000 rayls (1.25 - 1.75 Mrayls)

Reflection of an ultrasound wave depends upon a difference in the acoustic impedances at the boundary between the two media.

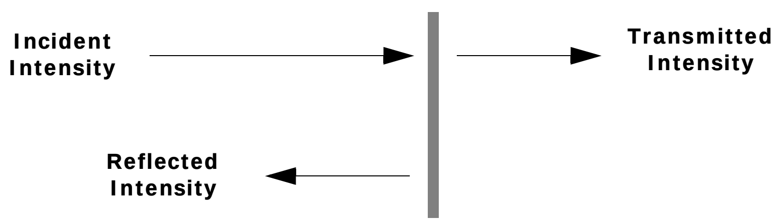
Reflection and Transmission

Incident Intensity The intensity of the sound wave at the instant prior to striking a boundary.

Reflected Intensity The portion of the incident intensity that, after striking a boundary, changes direction and returns back from where it came.

Transmitted Intensity The portion of the incident intensity that, after striking a boundary, continues on in the same general direction that it was originally traveling.

Units W/cm^2 (they are all intensities!)



Equation incident intensity = reflected intensity + transmitted intensity

"Conservation of energy" occurs at a boundary.

Reflection With Normal Incidence

With *NORMAL* incidence:

- **Reflection** occurs only if the two media at the boundary have **different acoustic impedances**.

With greater impedance differences between the two media, the greater the IRC and the greater amount of reflection.

$$\%\ \text{Reflection} = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]^2$$

Transmission With Normal Incidence

With *NORMAL* incidence: These are simply reflection questions, whatever remains after transmission, must be reflected!

Reflection & Transmission With Oblique Incidence

Extremely complex physics regarding transmission & reflection with obliquity.

I Don't Know! Transmission and reflection **may** or **may not** occur with oblique incidence, but there are no "simple" rules.

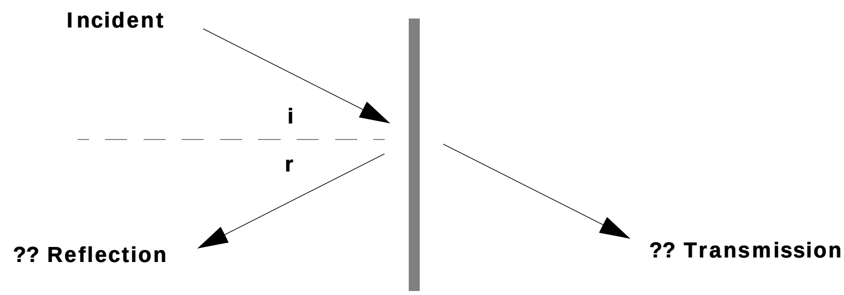
What we *DO* know with *oblique* incidence:

Remember

With oblique incidence, we are uncertain as to whether reflection will occur. Simply say "I don't know!"

Incident Intensity = Transmitted + Reflected

Reflection Angle = Incident Angle



Specular reflections arise when the interface is smooth.

Refraction

Definition Refraction is *transmission with a bend*.

Occurs when two conditions are met :

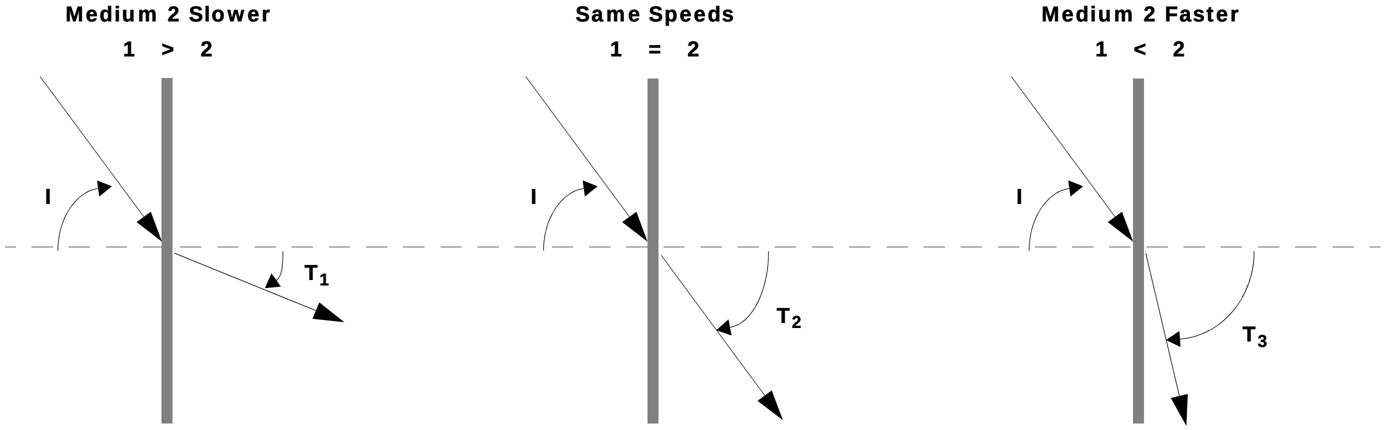
1. oblique incidence & 2. **different propagation speeds**

Equation The physics of refraction are described by **Snell's Law**.

$$\frac{\text{sine (transmission angle)}}{\text{sine (incident angle)}} = \frac{\text{propagation speed 2}}{\text{propagation speed 1}}$$

Examples If propagation speed 2 is *less* than propagation speed 1, then the transmission angle is *less* than the incident angle. ψ

If propagation speed 2 is *greater* than propagation speed 1, the transmission angle is *greater* than the incident angle.



Range Equation

When know the time-of-flight, we can determine the distance.

Ultrasound systems measure "*time-of-flight*" and relate that measurement to distance traveled.

Since the average speed of US in soft tissue (**1.54 km/sec**) is known, the time-of-flight and distance are directly related. ψ

Time-of-flight The time needed for a pulse to travel **from** the transducer to the reflector and **back** to the transducer is called:

» the **go-return time** ψ or the **time-of-flight** ψ

Equations

$$\text{distance to boundary (mm)} = \frac{\text{go-return time } (\mu s) \times \text{speed } (mm/\mu s)}{2}$$

In soft tissue:

$$\text{distance to boundary (mm)} = \text{time } (\mu s) \times 0.77 \frac{mm}{\mu s}$$

The 13 Microsecond Rule

Time-of-Flight	Reflector Depth	Total Distance Traveled
13µs	1cm	2cm
26µs	2cm	4cm
39µs	3cm	6cm
52µs	4cm	8cm

Axial Resolution

Resolution — The ability to image accurately (*accuracy*, not merely *quality*)

Axial Resolution — The ability to distinguish two structures that are close to each other **front to back**, **parallel to**, or **along** the beam's main axis.

Synonyms — longitudinal *or* axial

Units — mm, cm — all units of distance

With shorter pulses, axial resolution is improved.

The shorter the pulse, the smaller the number, the better the picture quality.

Changed by sonographer — No, a new transducer is needed to change axial resolution.

Note — "Short pulse" means a short spatial pulse length *or* a short pulse duration.

Ultrasound transducers are designed by the manufacturers to have a minimum number of cycles per pulse, so that the numerical value is low and the image quality is superior.

Typical Values — 0.05–0.5 mm

Hint — pulse duration & pulse duration are determined by the excitation voltage of the transducer crystal

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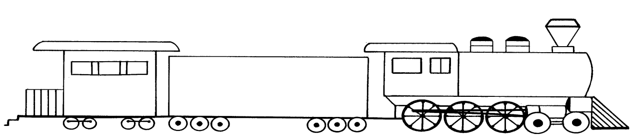
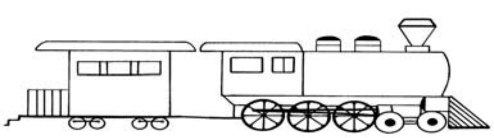
Equation

$$(\text{Axial resolution (mm)}) = \frac{\text{spatial pulse length (mm)}}{2}$$

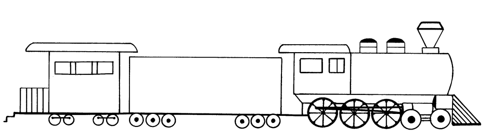
For soft tissue:

$$\text{Axial resolution (mm)} = \frac{0.77 \times \#\ \text{cycles in pulse}}{\text{frequency (MHz)}}$$





Less ringing (fewer cycles in pulse)



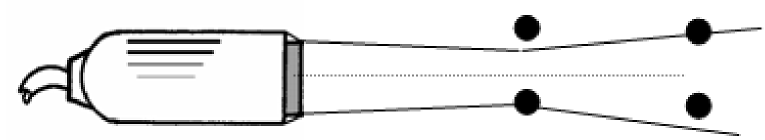
Higher frequency (shorter wavelength)

Lateral Resolution

Definition the minimum distance that two structures are separated by **side-to-side** or **perpendicular to the sound beam** that produces two distinct echoes.

Synonyms **L**ateral **A**ngular **T**ransverse **A**zimuthal

LATA resolution.



Units mm, all units of length

smaller number, more accurate image

Note Since the beam diameter varies with depth, the lateral resolution also varies with depth.

See question #65 in the comprehensive exam.

The lateral resolution is best at the focus or one near zone length (focal depth) from the transducer because the sound beam is narrowest at that point.

Note When two side-by-side structures are closer together than the beam width, only one wide reflection is seen on the image.

Note **Lateral** resolution is usually not as good as **axial** resolution because US pulses are wider than they are short.

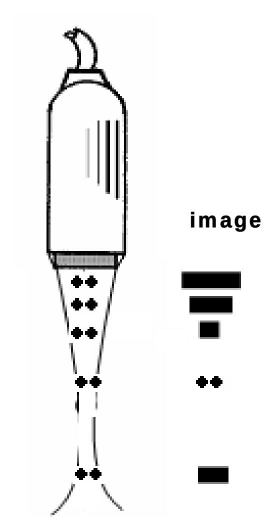
Be aware of the term "**POINT SPREAD ARTIFACT**"

Hint

Lateral resolution is approximately equal to beam diameter.

Lateral resolution at a variety of depths can be assessed with a test phantom by measuring the width of a reflection created by a pin in the phantom.

Wider reflections at depths further away from the focus exhibit poor lateral resolution.



Focusing

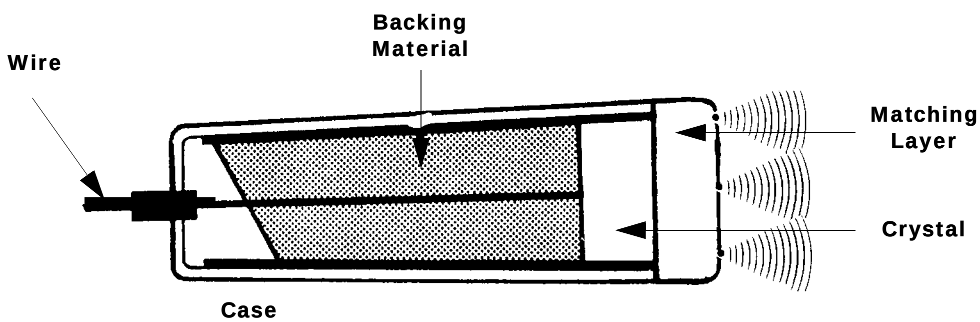
Results in:
1. a narrower “waist” in the US beam.
2. a decrease in focal depth (the focus is shallower).
3. a reduction in the size of the focal zone.

Effective mainly in the near field and the focal zone.

HINT (maybe) **FOCAL DEPTH = (Diameter^2) / (4 x wavelength)**

Electronic Focusing Phased array technology provides **dynamic**, **variable** (**adjustable**) **focusing or multi-focusing**.

Transducer Architecture



Active Element The piezoelectric crystal.

Case Protects the internal components from damage and insulates the patient from electrical shock.

Wire Each active element in a transducer requires electrical contact so that the voltage from the US system can excite the crystal to vibrate thereby producing an ultrasonic wave. Similarly, during reception the sound wave deforms the crystal, producing a voltage. The voltage is sent back to the ultrasound system for processing into an image.

Matching Layer Recall that impedance differences result in reflection at boundaries. The matching layer has an impedance between those of the skin and the active element to increase the percentage of transmitted US **between** the active element and the skin. Gel’s impedance is in between those of the matching layer and the skin.

The matching layer is **one-quarter wavelength** thick.

Impedances: PZT > matching layer > gel > skin

Damping Element or Backing Material

A material that is bonded to the active element that limits the "ringing" of the PZT. Commonly made of epoxy resin impregnated with tungsten.

Damping material - advantages:

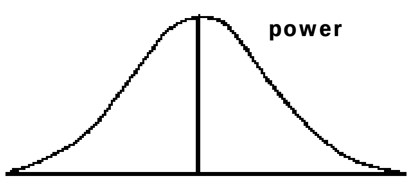
- » shortens spatial pulse length, pulse duration
- » decreases numerical value of axial resolution
- » improves axial resolution & picture accuracy

Damping material – also causes:

- » decreased transducer's sensitivity
- » increased bandwidth (**range of frequencies**) in the pulse - also called wide bandwidthψ
- » decreased "Q" factor. Imaging probes are low-Q

Bandwidth and Quality Factor

Bandwidth



It is uncommon for a transducer to emit a sound beam with only a single pure frequency. Rather, the pulse is more like a sound 'click' and contains a range of frequencies below and above the main frequency.

The bandwidth is the range of frequencies between the highest and the lowest frequency emitted from the transducer.

Quality Factor

A **unitless** number representing the *degree of damping*. Imaging transducers are **low-Q** transducers when compared to therapeutic transducers because imaging transducers use backing material.

The Q-factor of typical imaging transducers can be approximated by the number of cycles in the pulse produced by the transducer (approximately 2 - 4).

Equation

$$\text{quality factor} = \frac{\text{resonant frequency (MHz)}}{\text{bandwidth (MHz)}}$$

When Q-factor is low (imaging probe):

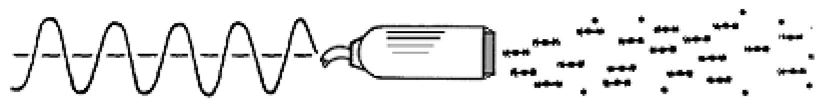
1. damping is effective
2. pulse length & duration are short
3. bandwidth is wide
4. axial resolution is improved

Transducer Frequencies

What determines the resonant frequency of a transducer?

Continuous Wave Transducers

Sound wave's frequency equals the frequency of the voltage applied to the PZT by the machine's electronics.



Pulsed Transducers

The pulse repetition frequency (PRF) is determined by the number of electrical pulses the US machine delivers to the active element.

The frequency of the US for a pulsed txr is determined by 2 factors:

1. the **thickness** and
2. the **propagation speed** of the piezoelectric material.

» propagation speed for PZT is approx. 4-6 mm/μs.

Higher Frequency	Lower Frequency
thin crystal	thick crystal
fast PZT	slow PZT

Equation

$$\text{frequency (MHz)} = \frac{\text{materials propagation speed}}{2 \times \text{thickness (mm)}}$$

Note

- The thickness of **the PZT crystal equals ½ of the wavelength** of sound in the crystal.
- The thickness of the **matching layer is ¼ of the wavelength** of sound in the matching layer.

Sound Beams

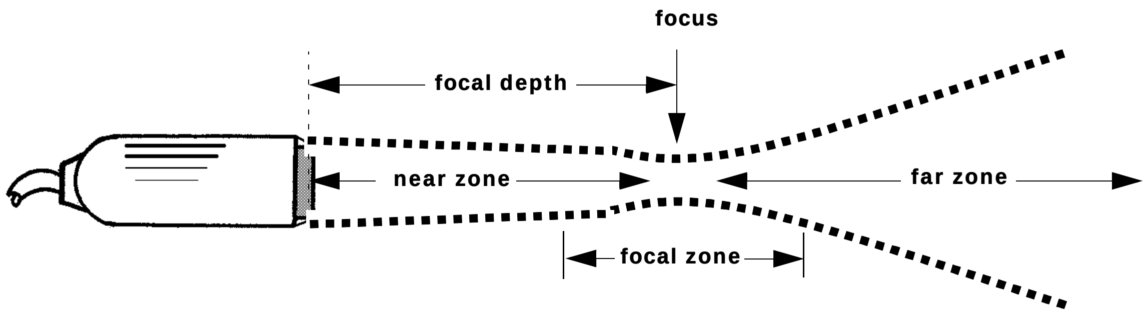
Beam width — **RULE: Narrow beams create better images**

As sound travels, the width of the beam changes:

» starts out at exactly the same size as the transducer diameter,

» gets progressively narrower until it reaches its smallest diameter, and then

» it diverges



Focus *or* **Focal Point** — The location where the beam reaches its minimum diameter.

Focal Depth - the distance from the transducer face to the focus. Also called **focal length** or **near zone length.**

Near Zone (Fresnel Zone) — The region or zone in between the transducer and the focus. Sound beams **converge** in the near zone

Far Zone (Fraunhofer Zone) — The region or zone deeper than the focus, beyond the near field.ψ Sound beams **diverge** in the far zone.

NEAR ZONE	FAR ZONE
short name	long name
Fresnel	Fraunhofer

Focal Zone — The region surrounding the focus where the beam is “sort of narrow” and the picture is relatively good.

Note — **For an unfocused continuous wave disc transducer:**

At the end of the near zone, the beam diameter is ½ the transducer diameter.

At two near zone lengths, the beam diameter is equal to the transducer diameter.

Focal Depth

Definition Distance from transducer to the focal point.

Determined by two factors:

1. **transducer diameter** *and*
2. **frequency** of the ultrasound.

HINT Compared to beams with a shallow focus, beams with a deep focus have a lower intensity at the focus.

SHALLOW FOCUS	DEEP FOCUS
small diameter	large diameter
low frequency	high frequency

Equation

$$\text{Focal Length (cm)} = \frac{(\text{transducer diameter})^2 \times \text{frequency}}{6}$$

Sound Beam Divergence

Definition Describes the spread of the sound beam in the deep far zone.

Determined by two factors:

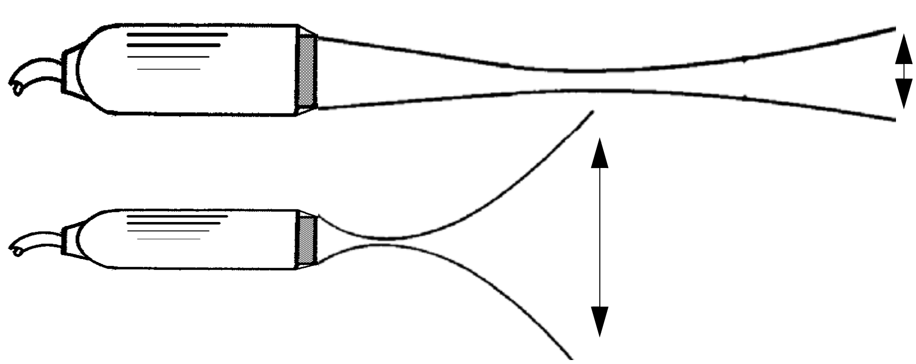
1. the **transducer diameter** *and*
2. the **frequency** of the ultrasound

Hint Numerical question: In the far field, beam is narrow (lateral resolution is *best)* with large diameter, high frequency sound. In the far field, beam is wide (lateral resolution is *worst)* with small diameter, low frequency sound.

LESS DIVERGENCE	MORE DIVERGENCE
narrower beam in far field	wider beam in far field
larger diameter crystal	smaller diameter crystal
high frequency	low frequency
improved lateral resolution in far field	degraded lateral resolution in far field

Larger diameter crystals producing higher frequency sound produce beams that diverge less in the far field.

Smaller diameter crystals producing lower frequency sound produce beams that diverge substantially in the far field.



Mechanical Scanning

Crystals Scanhead contains one active element

Steering The active element is moved by a **motor, oscillating crystal or mirror** through a pathway, automatically creating a scan plane.

Focusing Conventional or Fixed: curvature of the PZT or an acoustic lens focuses the beam at a specific depth.

Transducer Arrays

Array A collection of active elements in a single transducer.

Element A single slab of PZT cut into a collection of separate pieces called ***elements***.

Channel The electronic circuitry is connected to each ***element***.

Phased Arrays

Meaning **Adjustable focus** or **multi-focus**; achieved electronically.

Crystals, Steering & Focusing A collection of electric pulses, separated by miniscule time delays (10 ns), is delivered to **all** of the transducer's elements in various patterns. The patterns focus & steer the US beam **during transmission**. Thus, **focusing and steering are electronic**.

Real Time Imaging & Temporal Resolution

Real-Time Imaging The production of a motion picture. Frames displayed in a rapid fashion to give the impression of constant motion.

> Machines displaying both real-time images and Doppler at one time are called **duplex**.

Determined By

- Temporal resolution depends only upon **frame rate**. More images per second improves temporal resolution. ψ

Units Frame rate has units of **Hertz**, or "per second"

Determined by 2 factors

1. **Imaging depth - shallower image depth**
   » higher frame rate; improved temporal resolution
2. **Number of pulses per frame - fewer pulses**
   » higher frame rate; improved temporal resolution

HINT

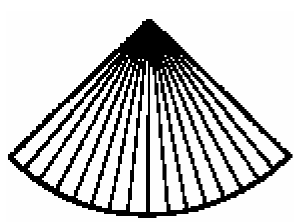
Frame rate is limited by 2 factors:
1) the speed of sound in medium, and/or
2) the depth of view.

Imaging Depth

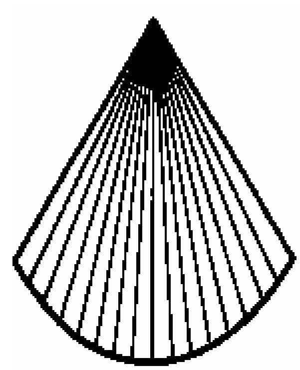
With regard to maximum imaging depth, *what will create a frame in less time*?

Shallow depth of view makes a frame faster, and improves temporal resolution.

Note If imaging depth of view is doubled (for example from 6cm to 12cm), the frame rate will be halved.



Shallow Imaging (less depth)
Higher frame rate
Better temporal resolution

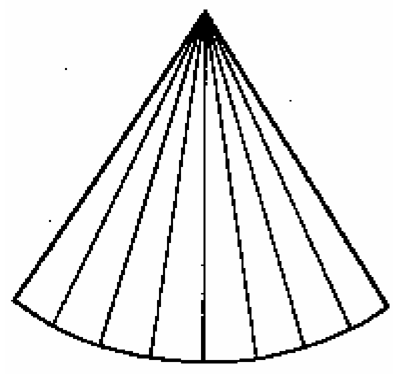


Deep Imaging (more depth)
Lower frame rate
Poor temporal resolution

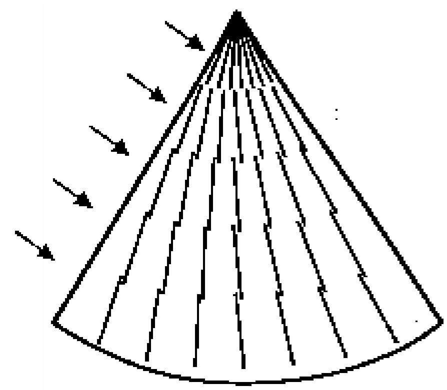
Single vs. Multi Focus

With regard to pulses per scan line, *what will create a frame with fewer pulses*?

Single focus uses fewer pulses, and improve temporal resolution. Single focus requires 1 pulse per scan line. Multi-focus, such as phased arrays, use more than 1 pulse per scan line and reduces temporal resolution.



Single Focus – fewer pulses
Higher frame rate
Better temporal resolution



Multi-Focus – more pulses
Lower frame rate
Poor temporal resolution

Image vs. Movie Quality

Improving image quality often degrades temporal resolution.

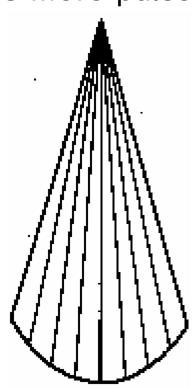
Multi-focus generally improves lateral resolution but reduces frame rate and temporal resolution.

Sector Size

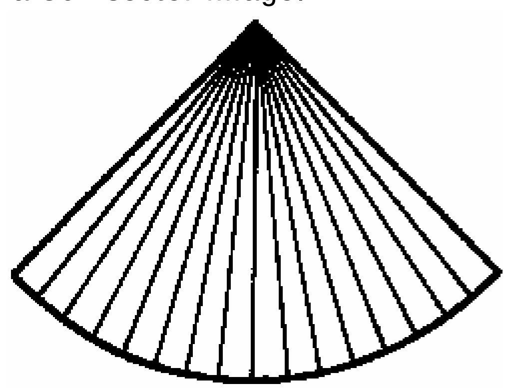
With regard to sector size, *what creates a frame with fewer pulses*?

Smaller sector angle images use fewer pulses, improving temporal resolution.

Creating an image with a 90° sector image requires three times more pulses than a 30° sector image.



Narrow Sector – fewer pulses
Higher frame rate
Better temporal resolution



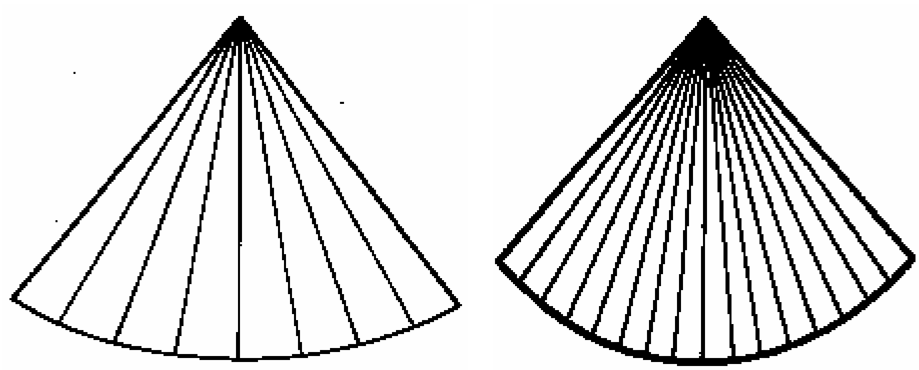
Wide Sector – more pulses
Lower frame rate
Worse temporal resolution

Line Density

With regard to line density, *what will create a frame with fewer pulses*?

Low line density images use fewer pulses, and have better temporal resolution. But, low line density degrades **spatial resolution** (also called detail resolution.)

Line density in a sector image is the number of scan lines per degree of sector. Line density in a rectangular image is the number of scan lines per centimeter. When the line density is low, temporal resolution is high.



Low Line Density – fewer pulses
Higher frame rate
Better temporal resolution

High Line Density – more pulses
Lower frame rate
Worse temporal resolution

Summary

High Temporal Resolution	Low Temporal Resolution
high frame rate	low frame rate
shallow	deep
fewer pulses per image	more pulses per image
single focusing	multi-focusing
narrow sector	wide sector
low line density	high line density
associated with better movie, but lower quality image	associated with poor quality movie, but higher quality image

chapter 4

Doppler

Doppler shift or Doppler frequency—the change in frequency resulting from motion between transducer anda moving interface in the body. Greater velocities create greater Doppler shifts.

difference between received and transmitted frequencies

Units Hertz, cycles per second—any units of frequency.

Typical values **20Hz-20kHz**ψ in clinical studies, audible.

- **Flow towards transducers** increased frequency
- **Flow away from transducers** decreased frequency

Frequency shift is always related to velocity.

Note We still use 2MHz to 10MHz transducers to perform a Doppler study, but the Doppler shift (which is a difference) ranges from 20–20,000Hz.

Demodulation Thus, the Doppler shift is a low frequency (10kHz) that 'rides' on top of the much higher 'carrier' transducer frequency (3MHz). The process of extracting the Doppler frequency from the transducer frequency is called **demodulation.**

Equation

$$\text{Doppler shift} = \frac{2 \times \text{reflector speed} \times \text{incident frequency} \times \cos(\text{angle})}{\text{propagation speed}}$$

Speed vs Velocity Doppler measures velocity, not speed.

Speed **magnitude** only.

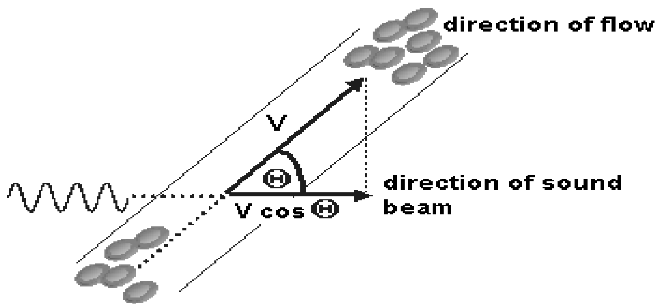
Velocity **magnitude** and **direction.**

Doppler frequency depends on direction. The magnitude of shift depends upon the **cosine of the angle** between the sound beam and the direction of motion.

Equation $\text{velocity (measured)} = \text{true velocity} \times \cos(\text{angle})$

At 0° or 180° between the direction of motion and the sound beam, the measured velocity is equal to the true velocity. At 90°, the measured velocity is zero because the cosine of 90° is zero. At angles between 0° and 90°, only a portion of the true velocity is measured.

Angle	Cosine
0 degrees	1
60 degrees	0.5
90 degrees	0



Continuous Wave Doppler

Number of crystals **Two transducer crystals**: one constantly transmitting, the other is continuously receiving

Advantage Able to measure very high velocities

HINT: Use of CW means no damping, narrow bandwidth and "hi-Q." Advantage to this is higher sensitivity and ease in detecting small Doppler shifts.

Disadvantage Echoes arise from entire length of overlap between the transmit and receive beams. This is **range ambiguity**.

Pulsed Wave Doppler

Number of crystals **One crystal,** alternates between sending and receiving.

Advantage Echoes arise only from the area if interrogation, the **sample volume**. This is called a **range resolution** or **range specificity** or **freedom from range ambiguity** artifact.

Disadvantage Aliasing

Aliasing

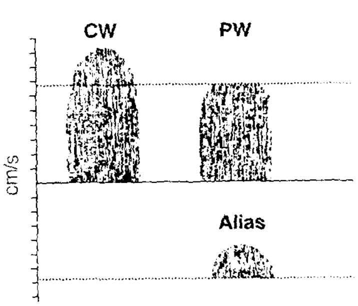
High velocities appear negative. T

Nyquist frequency The Doppler frequency at which aliasing occurs, equal to ½ the PRF. Also called Nyquist limit.

Equation **Nyquist limit (kHz) = PRF / 2**

Eliminating Aliasing To eliminate the unwanted effects of aliasing:

1. Change the Nyquist (change the scale).
2. Select a transducer with a lower frequency. This shrinks the spectrum.
3. Select new view with a shallower sample volume. This raises the Nyquist
4. Use continuous wave Doppler.
5. Select a new view so that the angle is further away from 0° and closer to 90°. This shrinks the spectrum.
6. Baseline shift (this is for appearance only.) Numbers 1 through 5 actually eliminate aliasing. Baseline shift simply makes it appear to have vanished.



Pulsed vs CW Doppler

Pulsed	Continuous Wave
minimum of one crystal	minimum of two crystals
range resolution	range ambiguity
limit on maximum velocity	unlimited maximum velocity
uses damped, low Q, wide bandwidth transducer	uses undamped, hi Q, low bandwidth transducer (provides higher sensitivity to small doppler shifts)

Imaging vs Doppler

Imaging	Doppler
normal incidence (90°)	0° or 180° incidence (oblique)
higher frequencies	lower frequencies
pulsed wave only	pulsed or continuous wave
at least one crystal	one (pulsed) or two (CW) crystals

Hints

Aliasing is an issue with Doppler, not with imaging

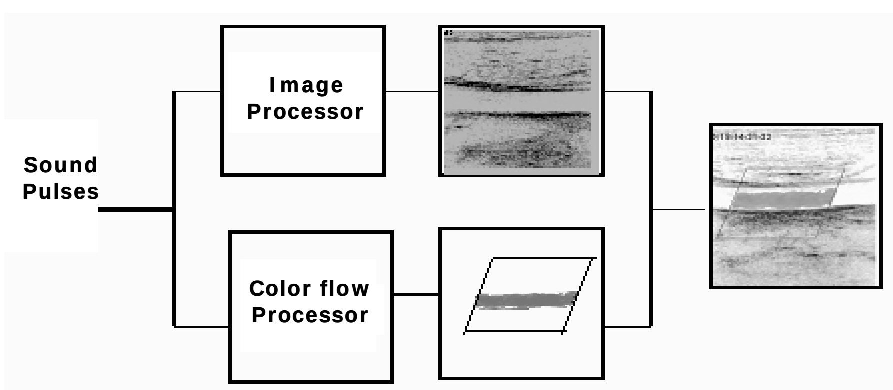
ASD flow is best visualized with low PRF and high freqency transducers. Low velocities require increased sensitivity.

Color Flow Doppler

Instead of just looking at velocities at a single location (with pulsed Doppler) or along a single cursor line (with CW Doppler.) Color Doppler is '2-D doppler' where velocities are coded into colors and superimposed on a 2-D image.

» black-and-white identifies anatomic structures

» color identifies blood flow velocities and function



Color Doppler is **pulsed** ultrasound technique & is subject to:

» **range resolution** and **aliasing**

Color Doppler provides information regarding direction of flow. It is semi-quantitative, so knowledge of angle is not especially important.

Average velocity Color Doppler reports **average or mean velocities**

Hint Color jet size is most affected by color doppler gain setting

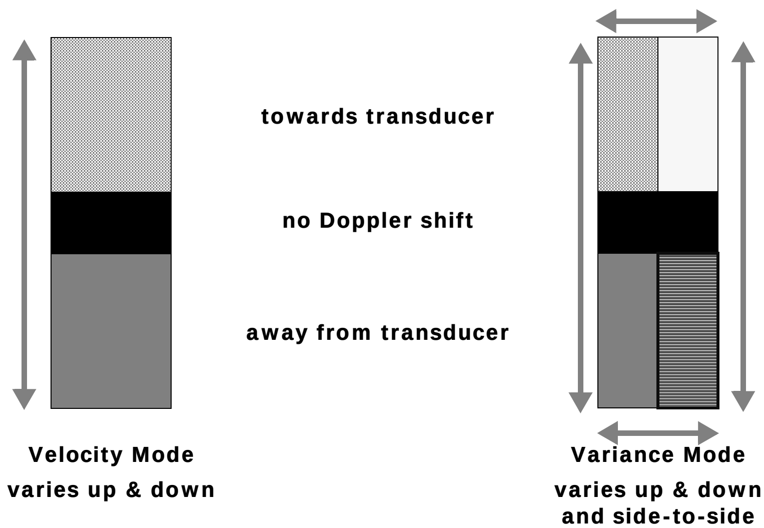
Color Maps

Doppler shifts yield information regarding velocity

Color Doppler uses a "dictionary" or look-up table to convert measured velocities into colors.

You can choose the dictionary:

- » **velocity** mode or **variance** mode



Velocity Mode The colors present information on **flow direction**.

If the color on our image appears on the top half of the color map, blood is moving towards the transducer. The higher the position on the color bar, the greater the velocity of the blood cells towards the transducer.

If the color on our image appears on the lower half of the map, blood is moving away from the transducer. The lower the position on the color bar, the greater the blood's speed moving away from the transducer.

Variance Mode Has a color map that also varies **side-to-side**.

The colors provide information on **flow direction** and **turbulence**. The System looks up the color based on the direction of flow and then adds another color (often green or yellow) to the picture if there is turbulence.

Left side—the flow **laminar** or **parabolic,** uniform and smooth. Often normal flow.

Right side—the flow **turbulent** or **disturbed**, random and chaotic. Often associated with pathology.

Doppler Packets

Multiple ultrasound pulses are needed to accurately determine red blood cell velocities by Doppler.

Packet This group is called a **packet**, or **ensemble length**.

Advantages More pulses in the packet has 2 advantages:

1. Greater accuracy of the velocity measurement
2. Sensitivity to low flows is also increased.

Disadvantages More pulses in the packet has this disadvantage:

1. Frame rate & temporal resolution is reduced.

Note The packet size must balance between accurate velocity measurements and temporal resolution.

Hint Spectral doppler (pulsed & CW) measures peak velocity.

Color flow measures mean velocity.

Color Power Doppler

Color Doppler where the amplitude is measured rather than direction and velocity. Also energy mode, color angio.

Advantages ψ

1. Increased sensitivity to low flows, e.g.: ASD flow
2. Not affected by Doppler angles, unless the angle = 90°
3. No aliasing (remember, we ignore velocity information!)

Limitations ψ

1. No measurement of velocity or direction
2. Lower frame rates (reduced temporal resolution)
3. Susceptible to motion, **flash artifact**.

Spectral Analysis

An echo returning after striking mass of moving blood cells is a complex signal with many Doppler shifted frequencies.

Spectral analysis is performed to extract the individual component frequencies of the complex signal.

Current methods **For spectral Doppler** - Fast Fourier Transform (FFT)

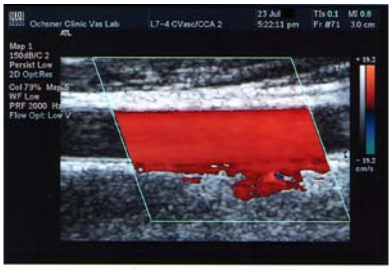
For color flow Doppler - autocorrelation or correlation function.

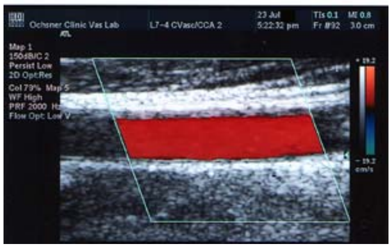
Autocorrelation is used with color Doppler because of the enormous amount of Doppler information that requires processing. Autocorrelation is slightly less accurate, but substantially faster, than FFT.

Doppler Artifacts

Doppler systems convert frequency shifts into colors and spectra. Frequency shifts generally arise from moving red blood cells. However, low velocity motion from pulsating vessel walls can also produce small Doppler shifts that 'bleed' into surrounding anatomy.

Wall filter





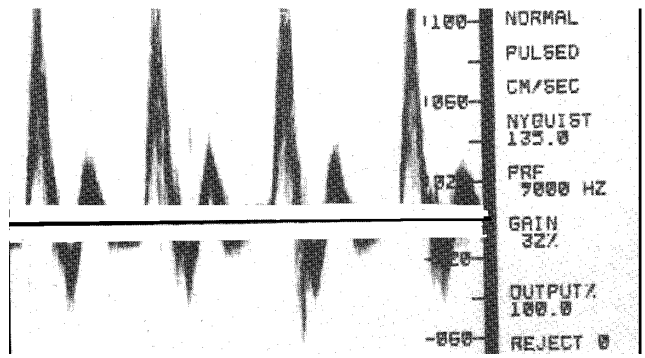
Eliminates low magnitude Doppler shifts that are created from moving anatomy rather than red blood cells. Also called a **high pass filter**.

Wall filters serve as a "reject" for Doppler. Wall filters exclude low level Doppler shifts **around the baseline**, while having no effect on large Doppler frequency shifts.

Wall filters are used to reject "**clutter**".

Color flash is called **ghosting** on the exam.

no spectrum around baseline due to wall filter



HINT

Reducing color Doppler gain will not cure ghosting artifact because red blood cell reflections are weaker than tissue reflections. Reducing color Doppler gain will eliminate reflections from tissues before those from blood cells.

chapter 5
Pulsed Echo Instrumentation

Transducer Output

Synonyms output gain, acoustic power, pulser power, energy output, transmitter output.

Changes in transducer output affect the brightness of the **entire image**.

Determined by the excitation voltage from the pulser.

Piezoelectric crystal vibrates with a magnitude related to pulser voltage.

Adjusted by sonographer Yes

Effect upon image When transducer output changes, every pulse transmitted to the body changes.

All reflections from structures in the body also change.

The brightness of the entire image changes.

Low Output

High Output

HINTS Increasing transducer output improves signal-to-noise ratio.

Affects patient exposure

Excessive output degrades axial resolution.

Receiver and Its Functions

Overall Function The signals returning from the transducer are extremely weak. The receiver boosts the strength of these signals, processes them and prepares them for display.

Order Amplification, compensation, compression, demodulation, rejection (**hint:** alphabetical order).

Amplification

Purpose Increasing the strength of all electrical signals in the receiver prior to further processing.

Synonyms receiver gain,

Adjusted by Sonographer Yes

Units dB, the ratio of the output electrical signal strength to the input electrical signal strength of the amplifier.

Effect upon image **Every signal is treated identically.** Thus, amplification changes the brightness of the entire image.

Note By itself, increasing overall gain cannot create an image with uniform brightness.

Compensation

Purpose Used to create image of uniform brightness from top to bottom.

Since attenuation is strongly related to path length, echoes returning from great depths have lower amplitudes than those returning from shallow depths.

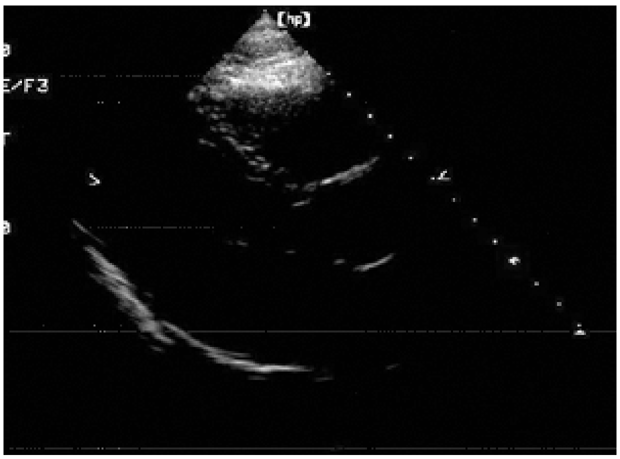
Effect upon image Compensation makes all echoes from similar reflectors appear identical regardless of their depth.

Synonyms Time gain compensation (TGC), depth compensation (DGC).

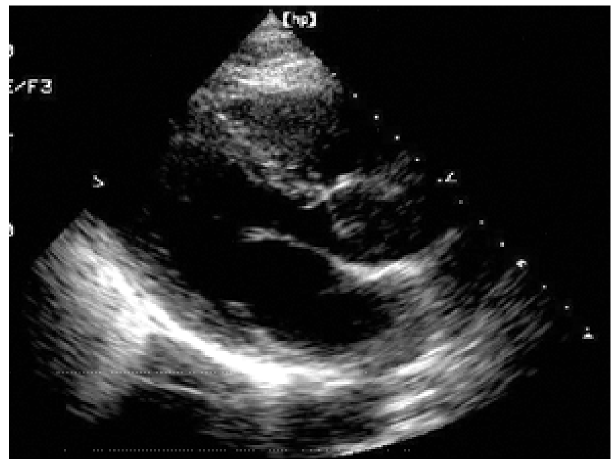
Adjusted by Sonographer Yes

Compensation treats echoes differently, depending upon the depth at which they arise.

Improper TGC



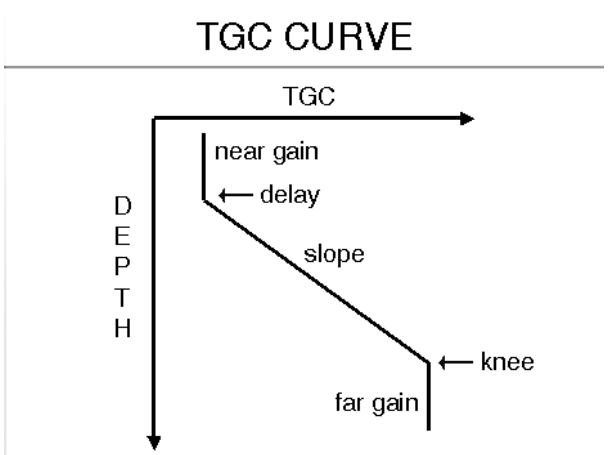
Proper TGC

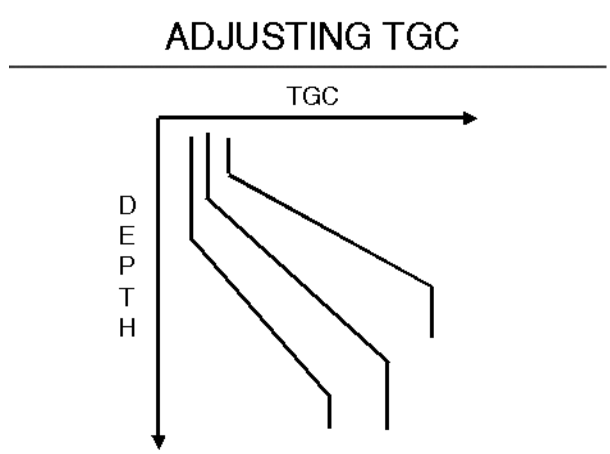


Note Compensation makes an image equally bright at all depths. Ask the question *"Is the image of uniform brightness from the top to the bottom?"*

TGC & Frequency Adjustments to TGC are related to transducer frequency:

- With a higher frequency transducer the beam undergoes more attenuation. Therefore, more TGC is used. On the diagram, the TGC curve is shifted upward & to the right.
- With a lower frequency transducer, the beam undergoes less attenuation. Therefore, less TGC is needed. On the diagram, the TGC curve is shifted downward & to the left.





Compression

Reducing the total range, the smallest to the largest signal.

Purpose Keeps signals within the operating range of the system's electronics and the gray scale within the range of what the human eye can see. Accomplished without altering the relative relationships between voltages; largest stays largest, smallest remains smallest

- **Decreases the dynamic range** of the signals.

Dynamic Range the ratio of the largest to the smallest strengths in a signal

Effect upon image Changes the gray scale mapping.

Adjusted by Sonographer Yes

Output Power vs. Receiver Gain

Output Power Affects image brightness by adjusting the strength of the sound pulse **sent to the tissues**. When the pulse is more powerful, all of the returning echoes from the body are stronger, and the image is brighter.

When the image is too bright due to high output power, the lateral and longitudinal resolution degrade.

Receiver Gain Affects image brightness by changing the amplification of the electronic signals **after returning to the receiver**. When amplification is increased, the electronic signals in the receiver are boosted, and the image will be brighter.

ALARA When an entire image is either too bright or too dark, changes in output power or receiver gain may correct the problem. As a first option, always choose the option that will **minimize patient exposure**. ψ

Use the **ALARA Principle**—**A**s **L**ow **A**s **R**easonably **A**chievable

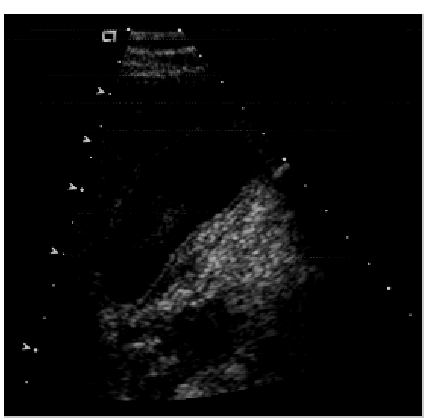


image too dark—first, increase receiver gain

image too bright—first, reduce output power

Bioeffects

no known bioeffects at standard imaging intensities

Thermal Mechanism

Temperature elevation via absorption resulting from interaction of biologic tissue and US. A second mode of thermal injury may result from localized scattering of acoustic energy, especially at inhomogeneities within the medium (Rayleigh scattering.)

Cavitation Mechanism

Microbubbles (gaseous nuclei) found in native tissues may be excited by US, taking the form of shrinking and expanding of the bubble. Potential of near total energy absorption where the nuclei exist may lead to thermal injury.

Stable cavitation - microbubbles expand & contract

Transient cavitation - microbubbles burst

The Final Word for Physics

As an ASCeXAM Review Course participant, you have complementary access to our internet based practice physics question website.

Follow these directions:

1. By Friday, you will receive an e-mail from me containing an ‘Email’ and ‘password’
2. go to my website ***www.esp-inc.com***
3. click on the word ‘***X-Zone***’ and scroll to the bottom of the page
4. enter the ‘Email’ and “password’ in the login to X-zone box and you will have access.

chapter 6

Physics Board Questions

1. What would you do to decrease far field divergence?
) a) use a smaller transducer b) use a lower frequency transducer
c) increase the compression d) use a higher frequency transducer
e) reduce the far field gain

d) Use a higher frequency transducer. Less divergent beams are created with higher frequency transducers and larger diameter crystals. This improves lateral resolution in the far field.

2. What would you do to decrease aliasing?
a) image by decreasing the nyquist limit b) image with a higher frequency transducer
c) use pulsed rather than CW Doppler d) image in a view with a shallower depth
e) decrease the gain

d) image in a view with a shallower depth. This increases the PRF and the Nyquist limit. Aliasing is less likely with a higher Nyquist.

3. A patient is evaluated with a TEE for possible severe mitral regurgitation. Which color Doppler setting will decrease the jet area on TEE from the initial image?
a) Lower the pulse repetition frequency b) increase the Nyquist limit
c) increasing the Doppler gain d) increase compression
e) decrease the reject

b) increase the nyquist limit. Increasing the Nyquist limit will make the system less sensitive to low velocities. Since the edges of a jet are low velocities, the jet will appear smaller. NOTE: This is the converse of a 2006 question about visualizing low velocity flow (ASD flow). To increase the sensitivity to low flow, use a lower PRF. To decrease the sensitivity to low, use a higher PRF.

4. What is the wavelength of 2 MHz sound in soft tissue?
a) 1.54 mm b) 0.75 mm c) 0.75 cm d) 0.75 m e) 0.77 s

b) The wavelength of sound in soft tissue equals 1.54 mm divided by the frequency (with units of MHz). 1.54 mm divided by 2 equals 0.77 mm.

5. What is the most common form of attenuation in soft tissue?
a) reflection b) refraction c) transmission d) attenuation e) absorption

e) Absorption. Of these choices, the primary component of attenation is absorption.

6. A patient is having aliasing trying to acquire the data with a velocity of 1.8 m/s. To get rid of the aliasing you would
a) use a higher frequency probe b) lower the PRF c) increase the gain
d) use more wall filterattenuation e) use baseline shift

e) Baseline shift is the best of all choices.

7. The major source of ultrasound information used to create a two-dimensional image is:
a) specular reflections b) raleigh scattering c) scattering d) backscatter

d) backscatter. Backscatter (diffuse) and specular reflections redirect sound energy back towards the transducer. Since backscatter redirects energy in many directions, the sound wave is more likely to be received by the transducer and used to create an image.

8. The speed of US in soft tissue is closest to:
a) 1540 km/sec b) 1.54 km/msec c) 1500 m/s d) 1540 mm/sec

c) Be careful with units. Sound travels approximately one mile per second in soft tissue. This is best approximated by 1,500 m/s, choice C.

9. Which of the following creates point spread artifact?
a) pulse width b) pulse duration c) pulse length d) pulse repetition frequency

a) Lateral resolution is determined by beam width. Point spread artifact is another way of describing suboptimal lateral resolution

10. Which of the following forms of resolution varies within the depth of a single frame?
a) axial b) contrast c) lateral d) harmonic

c) Lateral resolution is determined by beam width. Since beam diameter (or width) changes with depth, so too does lateral resolution.

11. As a result of ______________ the propagation speed increases.
a) increasing stiffness and increasing density b) increasing stiffness and decreasing density
c) decreasing stiffness and increasing density d) decreasing stiffness and decreasing density

b) Sound waves propagate at a higher velocity in stiffer media. They also propagate faster in media that are less dense. This is why sound travels rapidly in bone. Bone is quite stiff and has a relatively low density.

12. If the frequency of US is increased from 0.77 MHz to 1.54 MHz, what happens to the wavelength?
a) doubles b) halved c) remains the same d) 4 times greater

b) Recall that wavelength and frequency are inversely proportional, Thus, when frequency doubles, wavelength is halved.

13. What is the wavelength of 5 MHz sound in soft tissue?
a) 1.54 mm b) 0.7 mm c) 0.5 mm d) 0.3 mm

d) The wavelength of sound in soft tissue equals 1.54 mm divided by the frequency (with units of MHz). 1.54 mm divided by 5 equals 0.3 mm.

14. An ultrasound system creates a two dimensional image with a depth of view of 10 cm. The echocardiographer then switches to m-mode with the same depth of view. During both phases, the pulse repetition frequency is maximized. How does the pulse repetition frequency during m-mode acquisition compare to that during 2-D acquisition?
a) PRF for m-mode is 1/10th that of 2-D b) PRF for m-mode is half that of 2-D
c) PRF for m-mode is equal to that of 2-D d) PRF for m-mode is twice that of 2-D

c) maximum PRF is determined solely by the depth of view. Since the depths of view in both cases are equal, so too are the PRFs.

15. Refraction only occurs if there is:
a) normal incidence & different impedances
b) indirect intensity & different propagation speeds
c) oblique incidence & different propagation speeds
d) oblique frequency & identical impedances

c) Refraction is the redirection of a sound wave as it transmits from one medium to another. Refraction depends upon the media having different propagation speeds and the sound wave striking the boundary between the media at an oblique angle.

16. If the lines per frame is increased while the imaging depth is unchanged then:
a) frame rate increases b) number of shades of gray decreases
c) the frame rate decreases d) this cannot happen

c) When depth remains constant and the number of pulses in each image increases, more time is required to create each image. As a result, the number of frames created each second must decrease.

17. A sonographer adjusts an ultrasound machine to double the depth of view from 5 cm to 10 cm. If the frame rate remains the same, which one of the following also changed?

a) increased line density   b) wider sector
c) multi-focus imaging turned on   d) narrower sector

d) With constant frame rate, the time required to create a frame must be unchanged. Increasing imaging depth would increases the time needed to make a single image. The other action must act to counteract this increase. The only choice that decreases the time to make a frame is d) narrowing the sector

18. All of the following are true about tissue harmonics and contrast harmonics EXCEPT:

a) the effective path length of the harmonic signals are less than the fundamental signals
b) the harmonics are most likely to appear along the path of the beam's main axis
c) only contrast harmonics are created from non-linear behavior
d) only contrast harmonics are created with low mechanical indices

c)All harmonics are the result of non-linear behavior. Contrast harmonics are created from non-linear behavior of the microbubble. Tissue harmonics are created from the non-linear behavior of sound waves as they propagate.

19. A pulse emitted from a transducer travels in soft tissue and has a go-return time of 125 microseconds. What is the best estimate for the distance that the pulse traveled?

a) 125 cm   b) 19 cm   c) 10 cm   d) 5 cm

b) For each 13 us of go-return time, the reflector is 1 cm deeper in the body. Thus, the reflector in this example is located at a depth slightly less than 10 cm. The pulse, however, traveled from the transducer to the reflector and then back to the transducer. Thus, the total distance is closest to 2 x 10 cm or choice B.

20. Which of the following media attenuates sound waves the least?

a) bone   b) lung   c) soft tissue   d) air   e) water

e) Of the choices above, water is the only medium that sound travels through without attenuating substantially.

21. The major differences between pulsed and continuous wave Doppler modes is:

a. Aliasing and lack of range resolution   b. Angle dependence of the velocity measurement
c. Method of signal processing   d. All of the above

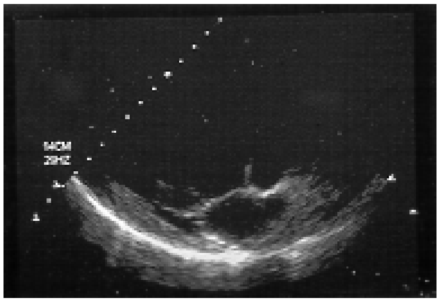
a) Only pulsed Doppler is subject to aliasing artifact, whereas only continuous wave Doppler suffers from range ambiguity.

22. Lateral resolution depends upon ____________________ and axial resolution depends upon ____________.

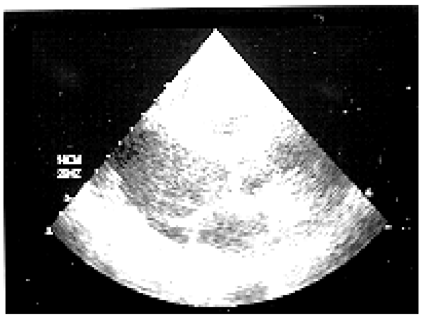
a) pulse length, pulse duration   b) pulse width, pulse repetition period
c) pulse width, pulse length   d) pulse repetition period, pulse length

c) Lateral resolution is determined by the beam width. Narrower pulses have superior lateral resolution. Axial resolution is determined by spatial pulse length. Shorter pulses provide superior axial resolution

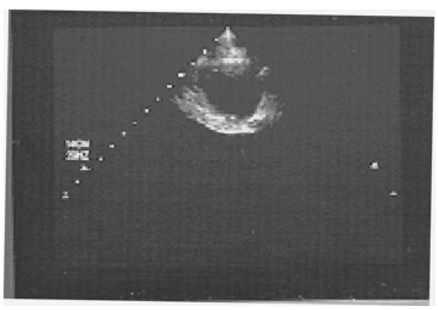
What Should You Do?



1. Which choice is best when the image on your ultrasound system displays reflectors only in a region far from the transducer but no reflectors in a region close to the transducer?
   a. Adjust the system's compensation
   b. Use a higher frequency transducer
   c. Decrease the output power



2. Which choice is best when the image on your ultrasound system is saturated (too bright everywhere)?
   a. Decrease the overall amplification or gain
   b. Use a higher frequency transducer
   c. Decrease the output power



3. Which choice is best when the image on your ultrasound system displays only reflectors in a region close to the transducer but not deep?
   a. Adjust the system's compensation
   b. Use a higher frequency transducer
   c. Increase the output power
   d. Adjust the reject level

Answers

1. a 2. c 3. a

chapter 7

Harmonics

Harmonic Imaging

Definition

Transmitting sound at a particular frequency (called the **fundamental frequency**), but creating an image from sound reflected at twice the fundamental frequency (called the **harmonic** or **second harmonic**).

Fundamental frequency

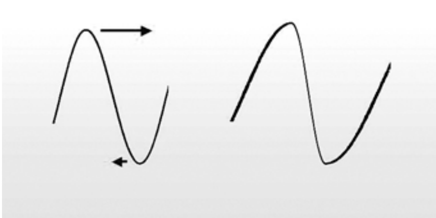
The frequency of the transmitted sound wave

Harmonic frequency

Twice the transmitted freq. Also called ‘second harmonic.’

Example

A transducer transmits a sound pulse with a fundamental frequency of 2MHz. In the harmonic mode, an image created from 4MHz sound reflections will be displayed.

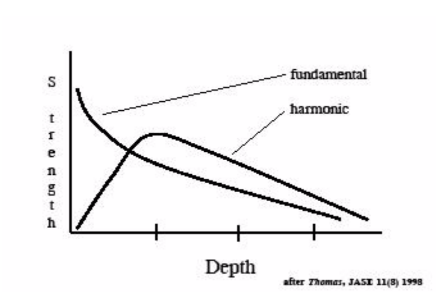


As a sound wave travels in tissues, a miniscule amount of energy is converted from the fundamental frequency to the harmonic frequency due to **non-linear behavior**.

When the fundamental image is suboptimal, the second harmonic may improve image quality. Harmonics work because the fundamental beam undergoes distortion (creating a bad image), while the harmonic signal distorts to a lesser extent.

TISSUE HARMONICS

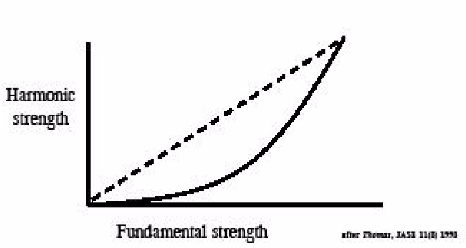
The non-linear behavior of sound propagating in the body causes energy to shift from the transmitted frequency to twice the transmitted frequency, the second harmonic.



The further the sound wave travels, the more energy is transferred to the second harmonic. New frequencies, that were not originally present in the transmitted wave, are added as the wave propagates.

The non linear behavior of sound propagating in the body also causes more harmonics where the fundamental beam is strong. Few harmonics exist when the beam is weak - thus no harmonic side lobes.

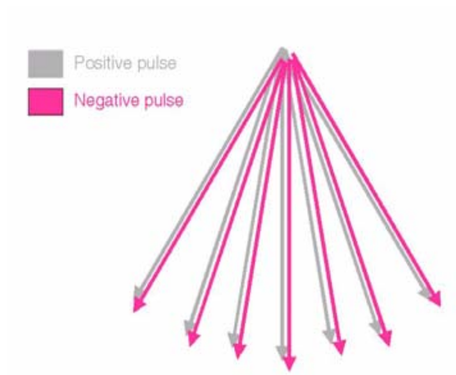
New frequencies magically "appear" in the sound beam after the beam is past the chest wall. The new frequency is twice that of the fundamental.



These new frequencies appear only where the beam is strong, in the main axis. Harmonics do not appear where the beam is weak, off axis and side-lobes. So, if we listen for the second harmonic only, the signal will arise only from the beam's main axis and will have substantially less distortion.

Echoes most likely to produce artifacts are least likely to produce harmonics.

Pulse Inversion Harmonic Imaging



a form of harmonic imaging where positive and negative pulses are transmitted down each scan line. The negative pulse is the ‘inverse’ of the positive pulse. Harmonic images are created with this process.

The major disadvantage of pulse inversion imaging is that the frame rate is half that of fundamental imagingψ. Thus, pulsed inversion imaging **degrades temporal resolution**, while **improving spatial resolution** (image detail accuracy) .

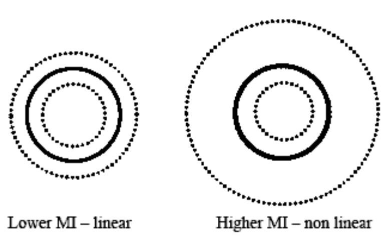
CONTRAST HARMONICS

Overall theory - send at a frequency, process reflections at twice the transmitted frequency. Transmitted sound strikes the bubble which behaves in a non-linear manner and creates harmonics.

Mechanisms for harmonic production

1. resonance - forced oscillations
2. bubble destruction

BUBBLE DISRUPTION



Creates harmonics

There is more bubble disruption with lower frequency & higher outputs (minimum pressure).

Mechanical Index - directly proportional to the creation of harmonics. The relationship between the shell and the internally trapped gas determines the contrast agent's stability and its longevity in the circulation.

$$\mathbf{MI = maximum\ rarefaction\ pressure\ /\ (frequency)^{1/2}}$$

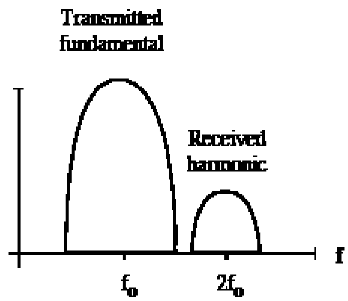
Shell

Shells are designed to trap the gas within the bubble and prolong the bubble's persistence in the circulation.

Gas bubbles without shells, (agitated saline), shrink and quickly vanish as the gas dissolves in blood.

Shells are also designed to be flexible, so that they can change shape.   More rigid shells tend to fracture.

INSTRUMENTATION



The outgoing pulse must have little or no energy at the harmonic frequency

Harmonic transducers have a narrower bandwidth

The US system needs to pass the harmonic frequency but eliminate all other frequencies.