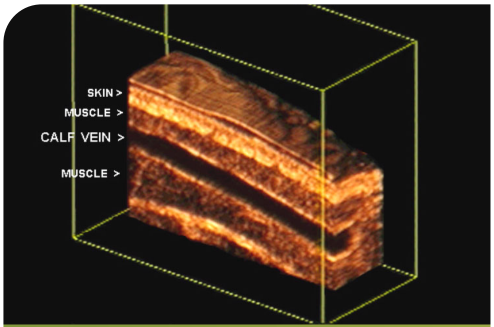
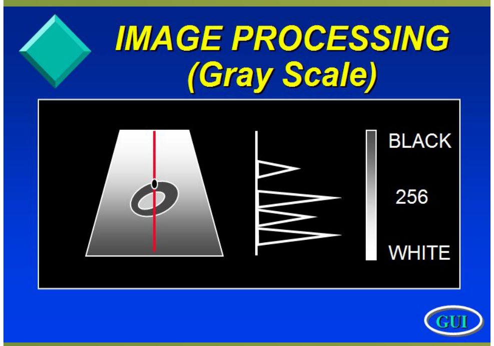
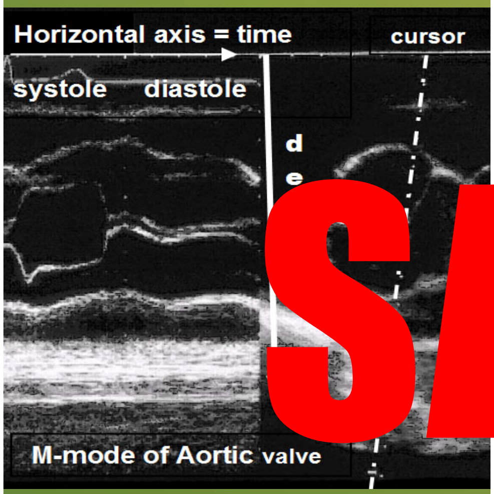
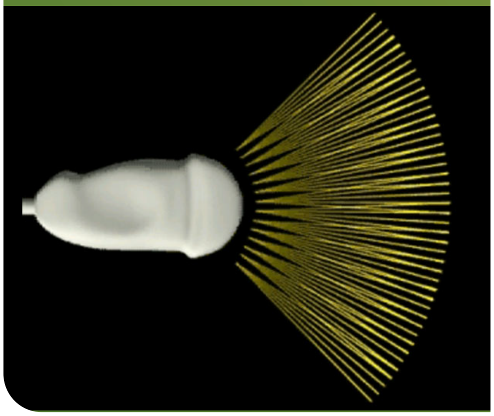








PAU-OL1-SPI4

ULTRA P.A.S.S.
Sonography Principles and Instrumentation
Registry Review Workbook
6th Edition

A Comprehensive Review System for the Ultrasound Registry

- *Updated Content based on ARDMS outline*
- *Over 160 Images, Diagrams, and Video clips*
- *[illegible] Access to the Online Media Center narrated videos and audio narration*
- *192 Self-Assessment Chapter Questions included*
- *Approved for a maximum of*
  17.0 AMA PRA Category 1 CME Credits™

Written by:
Lori Green, BA, RDMS, RDCS, RVT
and
Mark Swanson, RDMS, RVT

Now featuring the
Online Media Center

GULFCOAST
ULTRASOUND
INSTITUTE INC.

PAU-OL1-SPI4
Preparation **A**genda for **S**tudy **S**uccess

ULTRA P.A.S.S.
Sonography Principles and Instrumentation (SPI)

Registry Review Workbook

6th Edition

Compiled and Written by:

Lori Green, BA, RDMS, RDCS, RVT
and
Mark Swanson, RDMS, RVT

Published by:
GULFCOAST ULTRASOUND INSTITUTE INC

111 2nd Ave NE, #800
St. Petersburg, FL 33701
Tel: (727)363-4500
Fax: (727)363-0811
www.gcus.com

The Gulfcoast Ultrasound Institute, Inc.® is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to provide continuing medical education for physicians.

The Gulfcoast Ultrasound Institute, Inc. ® designates this enduring material for a maximum of 17.0 *AMA PRA Category 1 Credit(s)* ™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

LENGTH OF MATERIALS:
The estimated time to review all sections is approximately 13.5 hours. A post-lecture quiz should be completed after reviewing each section; Estimated time to complete all section quiz questions: 3.0 hours. Estimated time to complete CME quiz: 0.5 hour.
Total estimated time to complete the workbook as designed: 17.0 hours.

EDUCATIONAL NEEDS STATEMENT:
The planning committee has determined a need for this educational activity based on request from the medical community, expanded utilization of ultrasound, and lab accreditation requirements.

ENDURING MATERIALS COURSE OBJECTIVES:
Please see opening statements at each section

RELEASE INFORMATION: See Back Cover

COMMERCIAL SUPPORT DISCLOSURE: There was no commercial support involved in the planning, development, or implementation of this activity.

Disclosure of Relevant Financial Relationships

Authors: Lori Green, BA, RDMS, RDCS, RVT
President, Program Director, Planner, Content Reviewer, QI Task Force)
Gulfcoast Ultrasound Institute, Inc.
No relevant financial relationships to disclose.

Mark Swanson, RDMS, RVT
Senior Clinical Instructor, Gulfcoast Ultrasound Institute, Inc.
No relevant financial relationships to disclose

All presentations for this CME activity were reviewed and approved by members of the GUI CME Review Committee to determine content validity and to ensure that no conflicts of interest exist prior to the activity commencement or material compilation.

Disclosure of Individuals in Control of Content

In addition to the faculty listed the following individuals are recognized by GUI as being in control of content of this program:

James Mateer, MD, RDMS
Medical Director/Planner, QI Taskforce Subcommittee
Medical Director, Gulfcoast Ultrasound Institute
No relevant financial relationships to disclose

Charlotte Derr, MD, RDMS, FACEP (Co-Medical Director-planner & QI Task Force)
Assistant Professor of Emergency Medicine & Fellowship Director of Emergency Medicine
Ultrasound Fellowship Program
University of South Florida Medical School
Tampa, FL
No relevant financial relationships to disclose

Andreas Dewitz, MD, RDMS
Member of Advisory Board, QI Taskforce Subcommittee
Associate Professor of Emergency Medicine. Vice Chair of Ultrasound Education
Boston Medical Center. Boston, MA
No relevant financial relationships to disclose

Trisha Reo, RDMS, RVT
Program Coordinator, Planner, Content Reviewer, QI Task Force
Gulfcoast Ultrasound Institute, Inc.
St. Petersburg, FL
No relevant financial relationships to disclose.

PAU-OL1-SPI4- ULTRA P.A.S.S. Sonography Principles and Instrumentation Registry Review Workbook 6th Ed.
ISBN: 978-1-950973-96-5

Table of Contents

To Access the
Online Media Center
for Narration or Video Clips…

1. Point your browser to **https://www.gcus.com**
2. Log into your account
3. Select "My Activities" from the top menu
4. Click the "Media Center" button for: **PAU-OL1-SPI4**

Section 1:

PHYSICAL PRINCIPLES

SECTION 1: PHYSICAL PRINCIPLES

Objectives:

Upon completion of this module, you should be able to:

- Define sound and terms associated with the production of sound waves
- Recognize the relationships between frequency, wavelength, and propagation speed.
- State the properties of ultrasound waves and their effects upon each other.
- Identify physical units as they apply to diagnostic ultrasound
- Recall measurement dimensions and how they relate to diagnostic ultrasound

PHYSICAL PRINCIPLES

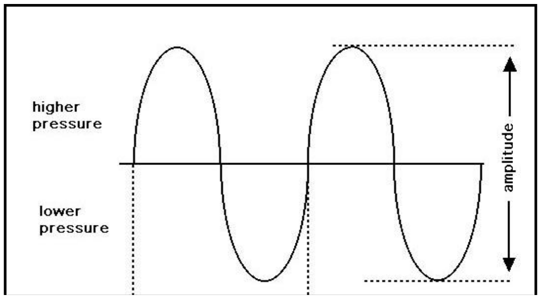
NATURE OF ULTRASOUND

Definition of Sound

Energy is the capacity to do work and is often transmitted in the form of waves. Sound is a form of energy that can be clearly differentiated form other types of energy such as electromagnetic energy because sound needs a medium in order to travel or propagate. Sound cannot travel in a vacuum. Sound is a traveling variation of acoustic variables. There are a variety of mediums that sound can travel through such as air, water, and tissues in the body. Also, because sound exists as physical movements of the particles in the medium, it is said to be mechanical.

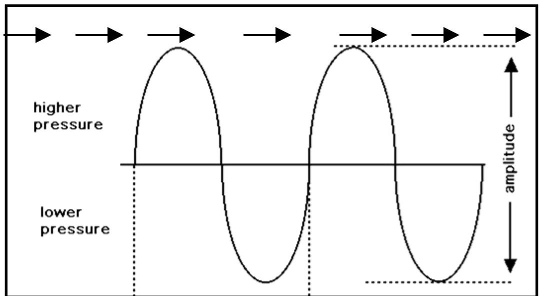
Propagation of Vibration

The particles of the medium through which the wave propagates or travels do not move; they only vibrate or oscillate. This is known as particle motion. Sound waves have the capability of carrying energy or information from one point to another. The effects the medium has on the sound wave are referred to as acoustic propagation properties.



Sound Wave

There are two types of waves: transverse and longitudinal. Sound waves propagate through a media. In tissue, sound waves cause particle displacement or pressure. As sound waves propagate, particles are pushed from their normal resting position and return after the sound waves have passed. Sound is a **longitudinal wave** where the medium particles vibrate parallel to the direction of the wave (waves that move in the direction of propagation). **Ultrasound** is a form of energy that is mechanically produced with waves that are longitudinal therefore, ultrasound is considered a **mechanical longitudinal wave** that travels in a straight line.



Particle motion parallel to motion of sound wave (Longitudinal wave)

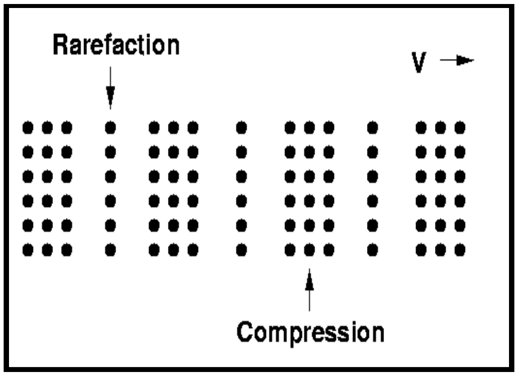
Waves have variables known as acoustic variables; changes to the medium caused by sound traveling through it.

Acoustic Variables

- **pressure**
- **density**
- **distance (movement)**
- **temperature**

Compression and Rarefaction

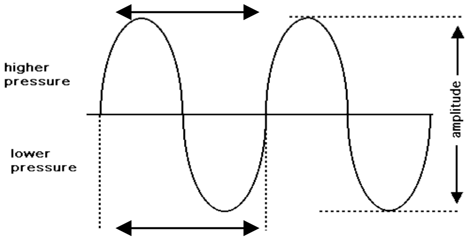
Density and pressure go through repetitive cycles of increasing and decreasing pressure as they propagate. The particle motion of the medium is the oscillation back and forth. The back-and-forth displacement of the source makes the effect of push-and-pull on neighboring molecules. Areas where the molecules are pushed together are called **regions of compression**. In these areas, the density (ρ) of the medium is slightly greater in comparison where the same medium without the disturbance caused by wave. On the other hand, areas of low pressure and density, where the molecules are drawn apart (or decompressed) as a result of the vibration molecular movement, are known as **rarefactions**.



Compression and Rarefaction

Areas of compression and rarefaction are areas of increased and decreased pressure.

Acoustic pressure is measured in Pascals (Pa). A complete wave cycle consists of one rarefaction and one compression. The slinky toy is an excellent example of compression and rarefaction. As you hold the slinky in your hand, the tightly coiled toy represents compression (high pressure and density); your hand supplies the energy to create a wave. When the toy becomes less tightly coiled, (rarefaction), it returns to its previous undisturbed state, completing one cycle.



One Cycle

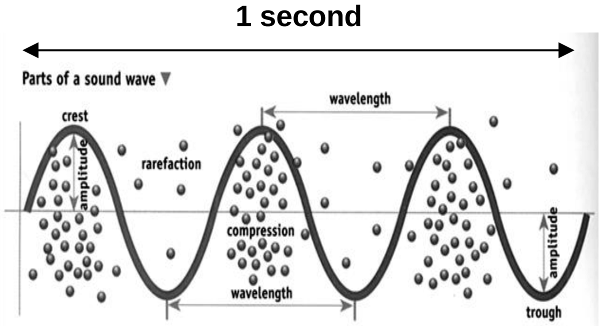
Sound is generally divided into three categories based on the frequency or the number of oscillations of the sound wave per second. These frequencies are measured in units of hertz. A hertz (Hz) is one cycle per second**. Frequencies below 20 Hz are called subsonic or infrasound.** Two examples are seismic waves and ocean waves.

Audible vs. *Ultra*sound

The spread of frequencies, which are detectable in the human audio range, is 20 to 20,000 Hz. Inaudible sound, commonly called ultrasound, has a frequency greater than 20,000 Hz. Diagnostic ultrasound frequencies range from 1 million to 20 million hertz.

FREQUENCY, WAVELENGTH & PROPAGATION SPEED

A practical way of expressing the temporal behavior of a sound wave is by plotting the pressure versus time at a single point in a medium. The result is a sine wave, and the number of times per second the disturbance is repeated at any point, or the **number of cycles per second is referred to as frequency (*f*). It is determined by the sound source only.**



Frequency (3 complete cycles)

The common units are hertz (Hz) and megahertz (MHz). Mega means million. **Period (*T*) is the time it takes for one cycle of compression and rarefaction to occur.** It is a small portion of one second. The units of measure for period are microseconds (µs) or any unit of time.

Frequency and period are reciprocals. As frequency increases, period decreases. As period increases, frequency decreases. Higher frequency = better resolution. Lower frequency = better penetration.

Section 2:

PROPAGATION OF ULTRASOUND THROUGH TISSUES

SECTION 2: PROPAGATION OF ULTRASOUND THROUGH TISSUES

Objectives

Upon completion of this module, you should be able to:

- Recognize the interaction of sound with tissue
- Describe the attenuation of sound and sources associated with attenuation
- State useful diagnostic frequency ranges
- Recognize and explain terminology associated with image characteristics

PROPAGATION OF ULTRASOUND THROUGH TISSUES

SPEED OF SOUND

The speed of sound in any medium is determined by the characteristics of the medium. An important characteristic to be considered again is the medium's stiffness or resistance to compression. Sound waves compress the medium and different tissues have a different resistance to being compressed. Another important factor is tissue density (ρ in g/cm^3 or kg/m^3). In other words, the transmission and propagation of sound in a medium depends on both the density and the stiffness of the medium.

Average Speed of Sound in Tissue

The propagation speed of sound in soft tissue is <u>1.54 millimeters per microsecond</u>. This is an average of multiple areas of soft tissue within the body. The propagation of sound through other various structures in the body listed below:

Range of Propagation Speeds in the Body
♦ Muscle – 1600 m/s ♦ Lung – 500 m/s ♦ Liver- 1560 m/s ♦ Bone – 3500 m/s ♦ Air – 330 m/s

All of these are considered to be soft tissue, so consequently 1.54 millimeters per microsecond is truly an average. Recall that the speed of sound in soft tissue can also be stated as 1,540 meters per second or 1.54 kilometers per second. Comparing the speed of sound in soft tissue to other areas within the body, the lungs, for example, have a speed of 0.5 millimeters per microsecond, fat is 1.45 millimeters per microsecond, and bone is 4.0 millimeters per microsecond. The higher speed in bone is because of its stiffness, <u>not</u> its density.

The increasing stiffness causes an increase in propagation speed. Speeds are lowest through gases, faster in liquids, and fastest through solids. See list below:

- Air – 0.33 mm/μsec
- Water – 1480 mm/μsec
- Lead – 2400 mm/μsec
- Aluminum – 6400 mm/μsec

REFLECTION

Characteristics of Acoustic Impedance

Whenever the ultrasound beam is incident on an interface formed by two materials having different acoustic impedances, some of the energy in the beam will be reflected and the remainder transmitted. **Reflection refers to interactions with particles or objects larger than the wavelength. The amplitude of the reflected wave depends on the difference in the impedance of the media.**

Impedance (Z) is equal to the density of the medium multiplied by the propagation speed. Based on this definition, it is clear that impedance is not dependent on frequency. The units of impedance are Rayls or MegaRayls (MRayls). The amount of ultrasound reflected or transmitted is dependent on impedance. The larger the impedance between two media interfaces, the greater the amount of ultrasound reflected back to the transducer. When two media have a similar or the same impedance, little or no reflection occurs. Typically, only 1 to 4% is reflected at most interfaces regardless of the impedance difference. **The five factors that affect the acoustic impedance of a medium are stiffness, compressibility, velocity, temperature, and density.**

Specular Reflection

Reflections that occur off a large, smooth surfaces are referred to as specular reflections. This is described as a "mirror like "reflection where sound is reflected back in one direction.

GULFCOAST ULTRASOUND INSTITUTE INC

Section 3:

ULTRASOUND TRANSDUCERS

SECTION 3: ULTRASOUND TRANSDUCERS

Objectives

Upon completion of this module, you should be able to:

- Recall the piezoelectric effect
- Identify the various types of transducers
- Recognize the advantages and disadvantages of the various types of transducers
- Outline the formation of the sound beam
- Recognize the types of resolution and discuss the various parameters that affect resolution.
- Recall the care and maintenance of transducers and the importance of maintaining them
- Outline the different methods of focusing

ULTRASOUND TRANSDUCERS

PIEZOELECTRIC EFFECT

Definition and Concepts

The term transducer is used to refer to a device with the capability of converting one form of energy to another. Ultrasonic transducers convert electrical signals into mechanical acoustic energy and acoustic energy into electrical signals. This principle is called ***piezoelectricity*** and was discovered by Pierre and Jacques Curie in the 1880s.

Piezoelectric Materials

Piezoelectric Effect describes the property of a material that creates a voltage when mechanically deformed. The Piezoelectric materials used to covert sound into electricity are Quartz (natural) and Lead Zirconate (PZT) and Polymer Piezoelectric materials (man-made). In manufacturing transducers are primarily made of ceramics (lead zirconate titanate), quartz, and polymers (polyvinylidene fluoride). During production, ceramics are made to be piezoelectric by placing them in a strong electric field while they are at a high temperature. In 1881 Curie showed that this process caused high frequency pressure waves to be produced.

Curie Point

The ***Curie Temperature*** is the temperature above which PZT loses all piezoelectric properties. Negative charges will align with the field and remain so when cooled. Transducers should never be autoclaved, or heat sterilized because temperatures above 350 degrees Celsius will cause the alignment of charges to be altered and cause loss of piezoelectricity.

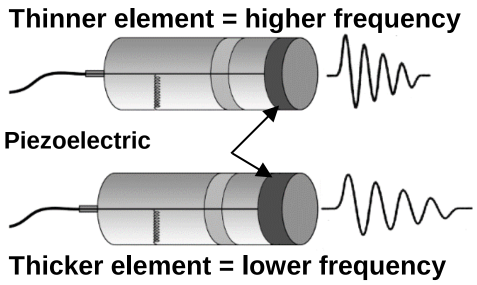
TRANSDUCER CONSTRUCTION & CHARACTERISTICS

Operating (Resonance) Frequency

Piezoelectric transducers have a resonant or *"center fire"* frequency at which it is most efficient in converting electrical energy to acoustic energy and vice versa. **A matching layer** bridges the significant acoustic impedance mismatch between the PZT and the skin to improve energy transmission. **Matching layer thickness is ¼ wavelength in crystal.**

CRYSTAL THICKNESS

The resonant frequency is also proportional to crystal thickness; the thinner the crystal, the higher the frequency. Also, the higher the piezoelectric material's propagation speed the higher the frequency.



SPEED OF SOUND in CRYSTAL MATERIAL

The resonance frequency is determined by the following formula:

$$f_0\,(\text{MHz}) = \frac{C_t\,(\text{mm}/\mu\text{sec})}{2 \times th\,(\text{mm})}$$

The propagation speed of the transducer (piezoelectric) material is $\mathbf{C_t}$ which is directly proportional to the resonance frequency of the transducer. The other factor in the formula is **th** or the thickness of the material which is inversely proportional.

Thickness Resonance of Crystals

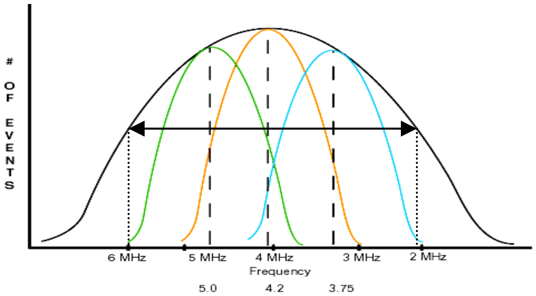
The most effective PZT crystal thickness is **½ the wavelength** in crystal. Typical element thickness is 0.2 mm to 2 mm.

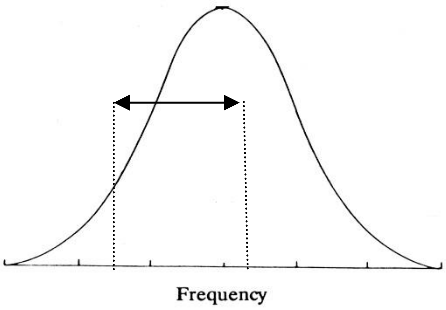
Transducers usually operate within or near the material's resonant frequency because the efficiency goes down as you move away from the resonant frequency. **Thinner PZT equals higher frequency and thicker PZT equals lower frequency. With pulse wave transducers, a short electrical spike is sent to the PZT crystal which causes it to vibrate. A faster speed in PZT will equal a higher frequency.**

Frequency Characteristics

BANDWIDTH

Bandwidth is the term that refers to the range of operating frequencies within a transducer. This is measured from the lowest to the highest frequencies. Broad or wide bandwidth transducers have a larger range of transmitted frequencies as the diagram below illustrates. The bandwidth is usually measured at the level of the arrow and the rest of the bandwidth below or beyond is less efficient (fewer events at that frequency) and therefore not usable. **The frequency of the transducer is the center frequency of the bandwidth and is the actual frequency at which the probe is most sensitive.**





Medium Bandwidth
(5 MHz to 3 MHz)

Quality Factor

A measure of frequency bandwidth is transducer Q, or quality factor. The Q is defined as the ratio of the transducer's center or resonant frequency to its bandwidth. For a fixed, center-fire frequency transducer, the wider the frequency bandwidth, the lower the Q Factor.

$$\textbf{Q Factor} = \frac{\textbf{Center Frequency}}{\textbf{Bandwidth}}$$

For example, if a transducer has a center fire frequency of 3.75MHz and a 4MHz bandwidth (from 2 to 6 MHz) it would have a Q Factor of 0.9375.

$$Q = \frac{3.75\text{MHz}}{4\text{ MHz}} = 0.9375$$

While a narrower bandwidth from 3 MHz to 5 MHz equals:

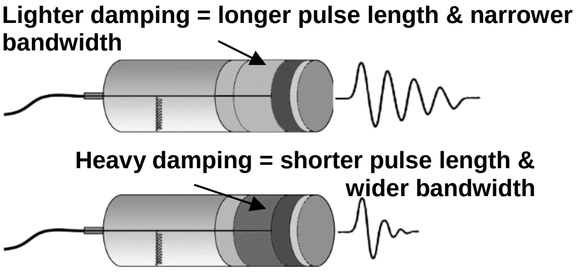
$$Q = \frac{3.75\text{MHz}}{2\text{ MHz}} = 1.875$$

Low Q transducers are used in pulse-echo ultrasound applications such as ultrasound imaging and have a wide bandwidth. Continuous Wave transducers have a High Q factor and a narrow bandwidth.

The performance of the transducer is also evaluated by its Q factor. A transducer with a high Q factor "rings" longer, creating a long pulse length. This results in a long ring down time and narrow range of frequencies or narrow bandwidth. This makes better transmitters and is used for therapeutic ultrasound and continuous wave Doppler. Low Q factor transducers have a short ring down time, wide frequency range, and make better receivers. These are used for pulse echo imaging as stated above. A dampened transducer produces a short pulse which contains a range or spectrum of frequencies instead of a unique pure frequency. Q factor is unit less and is used to describe the purity. Generally, the Q factor is equal to the number of cycles in the pulse.

Effect of Damping

As stated before, Bandwidth is the term that refers to the range of operating frequencies within the pulse of a transducer. For a given resonant frequency, the shorter the pulse duration, the wider the frequency bandwidth. The level of damping (backing) material can impact pulse length.



Short bursts of electricity are used to excite pulse-echo instruments. This causes a vibration or "ringing" of the transducer element at its resonant frequency. The vibration process sends a pulse or sound wave into the patient. The other side of the *piezoelectric effect* is the systems' ability to *"listen"* or receive an echo from the patient and convert it into an electrical signal that represents the tissue that reflected the sound.

If the transducer rings too long it diminishes the time the system dedicates to "listening" for the returning echoes, which causes poor axial resolution. For this reason, short pulses are desirable to obtain longer "receiving" times.

DAMPING (BACKING) MATERIAL

Backing material reduces vibrations from the crystal, shortens the pulse length, and improves axial resolution.
The damping material is located behind the piezoelectric crystal as illustrated in figure above.

Damping material needs to have two properties. Its acoustic impedance must be comparable to that of the piezoelectric element. This property reduces the reflections at the crystal-damping material interface so that any energy generated in that backward direction is transmitted out of the element.

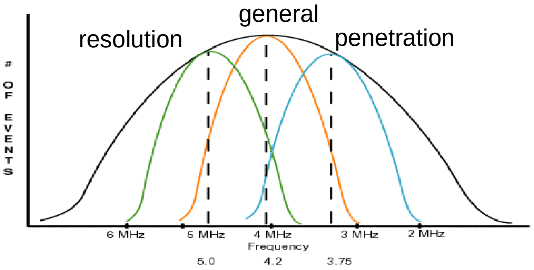
The other property of the material is that as those sound waves are transmitted into it, it must be able to absorb the energy thus "dampening "the vibrations of the piezoelectric element.

This reduction in pulse length causes an improvement in the axial resolution. However, this creates an undesired effect by decreasing the efficiency and sensitivity of the system. The efficiency is decreased as a result of decreased intensity of the output (the stronger the pulse the longer it would ring).

Multi-Hertz

Wide bandwidth transducers have a bandwidth of 70% or a Q factor of 1.4. This allows the same transducer to be operated at more than one frequency. The selectable frequencies must be within the bandwidth. The switching from one to another is often accomplished with the push of a button. Some systems display the specific frequency selected while others use *resolution, general & penetration* or similar notation.

.



There are several advantages to this type of transducer:

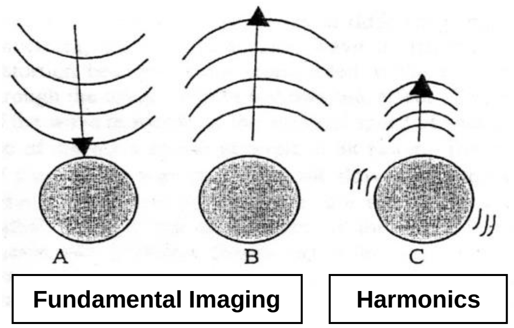
1. Having the ability to use the higher frequency for better resolution

2. Changing to the lower frequency for better penetration is easy and convenient.
3. Selectable frequencies for broad applications i.e., adult to pediatric imaging.
4. Require fewer transducers to cover frequency range, thus saving costs initially and on service contracts.

HARMONICS

There are several clinical benefits to harmonic imaging but to truly appreciate them and to apply them you need to understand the difference between harmonic and conventional imaging. Conventional imaging is the result of a transmitted and received sound pulse that is of a specific frequency range. The received pulse differs in intensity (weaker) from the transmitted pulse because as it travels through tissue it loses energy due to attenuation and absorption. When the system detects the returning pulse, in addition to the weaker returning signal of essentially the same frequency from the *"fundamental"* transmitted pulse, it detects other frequency signals that are generated from the tissue in response to the fundamental vibration.

This ***"harmonic"*** **frequency is double the transmit** frequency. There are multiple harmonic frequencies which are generated and detected in the positive and sub-harmonic range. **The strongest harmonic distortion occurs at twice the fundamental frequency. This is called the 2nd harmonic frequency. A 5MHz frequency will develop a second harmonic frequency at 10MHz**. Initially this phenomenon was created by introducing contrast *"micro-bubbles"* into the patient's circulation which created a resonant vibration that went from the bubble to the transducer.

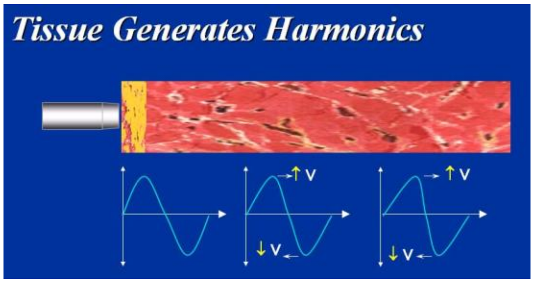


During A., the sound pulse arrives from the transducer. Then, during B., the echo returns from the bubble. Finally, during C., the bubble vibrates in response to the shock from the pulse, thus generating another signal, the harmonic signal, which also returns to the transducer. The system receives both echoes almost simultaneously, but it processes them and separates their components which results in a distinct harmonic signal.

Fundamental Imaging: ultrasound image created by processing the same frequency as the transmitted sound. **Fundamental frequencies follow linear characteristics. Harmonic Imaging: image created by utilizing only the reflections at twice the fundamental frequency. The fundamental frequency still exists but is suppressed. Harmonics are non-linear and will not cancel each other out. Only the fundamental frequency is available in the near field because Harmonics have not developed. Tissue Harmonics is strongest in the mid field.**

With contrast harmonics the larger molecule, created by the micro-bubble attaching to the red blood cell, has more surface area and thus creates a stronger reflected amplitude and unique backscatter pattern than the red blood cell alone. **Contrast agents create much stronger harmonics than tissue. Contrast Harmonics are generated during reflection.**

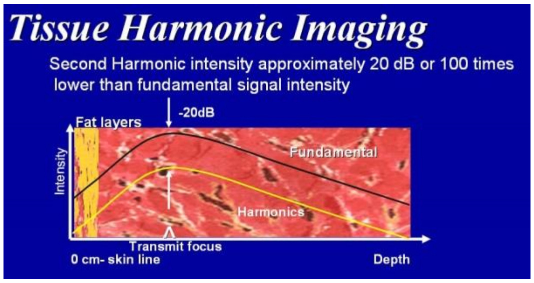
Ironically when manufacturers developed the instrumentation to detect and separate the contrast harmonics, they discovered that even when the contrast agent wasn't present in circulation, the *native tissue* generated a *harmonic* echo as well**. NTHI or *Native Tissue Harmonic Imaging* was coined. It arises not from micro-bubble vibration but from the tissue during non-linear pulse propagation.** The propagation is non-linear meaning the acoustic pulse compresses and stretches tissue but it is not linearly elastic. The effect on the sound pulse is that compressed tissue has a different speed of sound than the stretched tissue. Wave peaks travel faster than troughs.


Tissue Generates Harmonics

The acoustic pulse distortion continues and grows with depth creating the presence of harmonics. The signal that is generated then travels back to the transducer. This harmonic frequency has always been a component of the returning echo signal but prior to contrast investigation, systems were not optimized to process the *native tissue harmonic signal.* As described previously, the transmitted frequency is lower and the harmonic frequency is higher. In fact, it results in twice the fundamental frequency.

Video clip 3-a Harmonics

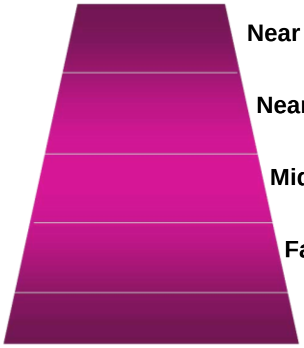
At some point the penetration and production of harmonics will be ineffective due to attenuation.


Tissue Harmonic Imaging

Second Harmonic intensity approximately 20 dB or 100 times lower than fundamental signal intensity

The best portion of the field of view for *tissue harmonic imaging* will be limited and is dependent on the tissue medium and the fundamental signal intensity.

ANATOMY OF HARMONIC DEVELOPMENT
TIME vs. DISTANCE TRAVELED



Near field = no harmonics
Near mid-field = > harmonics
Mid field = max harmonics
Far mid-field = < harmonics
Far field = no harmonics

Because of the weaker signal strength of tissue harmonics (100 times lower than fundamental signal intensity) a lower intensity signal generates minimal harmonics. This explains why harmonics can have a greater impact in cardiac imaging where the incident signal is around 420 mW/cm^2 while abdominal imaging uses an intensity of < 100 mW/cm^2.

GULFCOAST
ULTRASOUND
INSTITUTE INC

Section 4:

PULSE ECHO INSTRUMENTATION and IMAGING PRINCIPLES

SECTION 4: PULSE ECHO INSTRUMENTATION and IMAGING PRINCIPLES

Objectives

Upon completion of this module, you should be able to:

- Identify the general concepts of the range equation
- Recall pulsing characteristics including pulse repetition frequency, pulse repetition period, pulse duration, spatial pulse length, and duty factor
- Identify the various stages and components of pulse echo instruments
- Define dynamic range

PULSE ECHO INSTRUMENTATION and IMAGING PRINCIPLES

RANGE EQUATION

The range equation is the relationship between round trip pulse travel time and distance to reflector. This equation is based on several assumptions: first, that the direction of the echo is assumed to be in the same direction from which it was emitted, and secondly, that the speed of sound is constant in tissue. The ultrasound equipment does not measure the distance itself; instead it looks at travel time based on the assumed speed of 1.54 millimeters per microsecond. The distance to reflector is then calculated by one-half the propagation speed multiplied by the pulse round trip time. When determining the distance to the reflector, you may use 0.77, which is a constant, for one-half the speed of sound in soft tissue. Errors can occur because of the assumptions made. For example, if the speed is actually faster than 1.54 mm/μs, then the echo is placed too close; likewise if it's slower than 1.54 mm/μs, the echo is placed too deep.

PULSING CHARACTERISTICS

Various terms are used to describe pulsed echo and include pulse repetition frequency or PRF, pulse repetition period or PRP, pulse duration, duty factor, and spatial pulse length. Now let's review each of the characteristics of pulsed echo. Short pulses are used for imaging. **The pulser, which functions during transmission, creates electrical signals that excite the PZT. A pulse is a collection of cycles that travel together. The transmit time is the time the pulse is being emitted and the receive time is the time the ultrasound machine is listening for echoes returning from the body**.

Beam former functions include:

- Receives pulse from transducer
- Controls aperture (varies number of PZT crystals utilized)
- Creates delays for phasing
- Focuses and steers phased transducers
- **Digital beam former** is considered part of transmitter (pulser). It creates signals in digital form. Transmit pulses are encoded with binary information. Improve signal to noise ratio.

Pulse Repetition Frequency – PRF

PRF is the number of pulses transmitted in one second. It is the reciprocal of PRP, and its units are Hertz and Kilohertz. **Typical values are 1000Hz to 10000Hz. Determined by the sound source only and is adjustable by changing depth.**

Pulse Repetition Period

The time from the start of one pulse to the start of the next pulse, which includes the dead time or listening time, is termed pulse repetition period. The units used are seconds and microseconds (ms).

Pulse repetition period and pulse repetition frequency like frequency and wavelength have an inverse relationship. PRP is usually 100 to 1000 times longer than pulse duration. Both the PRF and the PRP are determined by the source. This is adjustable by the sonographer when the depth is changed. As depth increases, PRP is increases. The two elements of the PRP are the transmit time and the receive time (listening time) which can be controlled by selecting different depths. Typical values: 100μs to 1ms.

Pulse Duration

Pulse duration is how long it takes a pulse to occur or the transmit time while energy is going into the patient. **It is the time from the start to the end of the pulse. The receive time is the listening time as echoes are returning from the tissue and being recorded. Pulse duration is found**

GULFCOAST ULTRASOUND INSTITUTE INC

Section 5:

PRINCIPLES of PULSE ECHO IMAGING: DISPLAY MODES

SECTION 5: PRINCIPLES of PULSE ECHO IMAGING: DISPLAY MODES

Objectives

Upon completion of this module, you should be able to:

- State the difference between A-mode, M-mode, and B-mode.
- Recognize the advantages of the various imaging modes
- Identify scan speed limitations
- Perform range equation calculations and explain its relationship to pulsing characteristics
- Define temporal resolution

PRINCIPLES OF PULSE ECHO IMAGING

DISPLAY MODES

It is the use of pulsed echo that allows imaging to occur. For real time imaging, a wide variety of transducers can be utilized.

Also, there are different modes of pulsed wave that require a basic understanding and will be discussed in this section including: A-Mode, B-Mode and M-Mode.

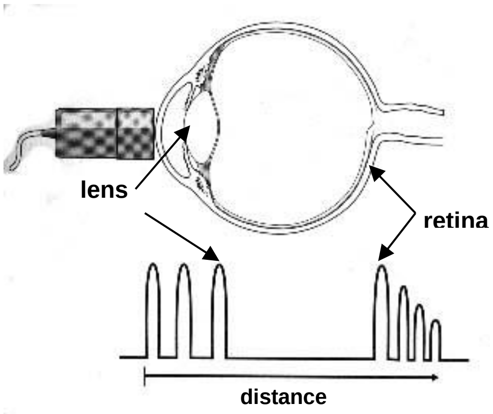
A-Mode:

A-Mode or ***amplitude*** mode is represented by a spike appearance. The amplitude of the spike is based on the reflected intensity received from the reflector. The further away the reflector is, the smaller the spike due to attenuation. Strong echoes create tall spikes. The vertical axis of the display corresponds to *amplitude* of the returning echoes and the horizontal axis corresponds to the distance from the probe. The display can also be rotated 90 degrees so the distance from the probe can correspond to depth. Some of the original ultrasound systems consisted of an oscilloscope so the examiner could visualize the A-mode of a structure to determine if the area of concern was cystic or solid.

Today accurate measurement of depth of interfaces and their separation is the major use of the A-mode. As you may realize, the accuracy would rely on axial resolution. Remember that the two things that affect axial resolution are the frequency and spatial pulse length. Many of the current A-mode transducers are between 10 – 20 MHz.

The advantage of A-mode is that it is inexpensive, easy to use, and durable. The disadvantage would be the required daily calibration for the depth and separation measurements. In addition, a two-dimensional image is not provided.

A-mode is seldom utilized except in ophthalmology. It is used in ophthalmology to measure the axial length (distance) from the lens to the retina to determine at what distance the image needs to focus and therefore what diopter (strength) lens should be implanted following cataract lens removal.

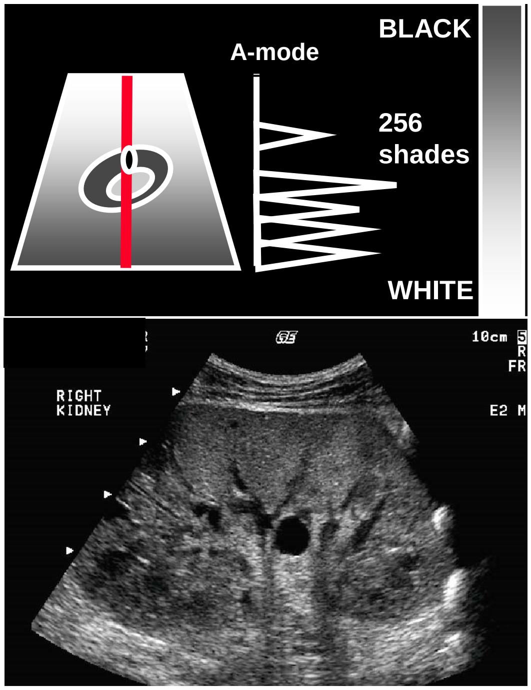


B-Mode:

B-mode or ***brightness*** mode is directly proportional to the strength or amplitude of the returning echo. The real time images are created rapidly and automatically with placement of the brightness dots based on the range equation and the amplitude of the reflected signal. **This is the normal viewing mode.** The higher the amplitude or the returning echo the brighter the corresponding dot on the display. The horizontal position of the brightness dot or corresponding pixel on the monitor is determined by the element that is responsible for the transmitted and detected pulse and the type of beam steering utilized by the transducer.

Real-time scanning frame rates and the extent of the field of view or scanning *“chevron”* (sector, curved, rectangular, trapezoid etc.) depends upon the type and operation of the transducer selected and the frequency.

Bi-stable (black & white) images, which were useful to determine cystic vs. solid, have been replaced by grayscale imaging displays. Grayscale has the ability to provide a range of intermediate intensities. Current equipment has from 64 to 256 shades of gray to correspond to a wide range of echo amplitudes. **The contrast determines the range of grays available.**



Grayscale image corresponding to diagram and amplitude assignment

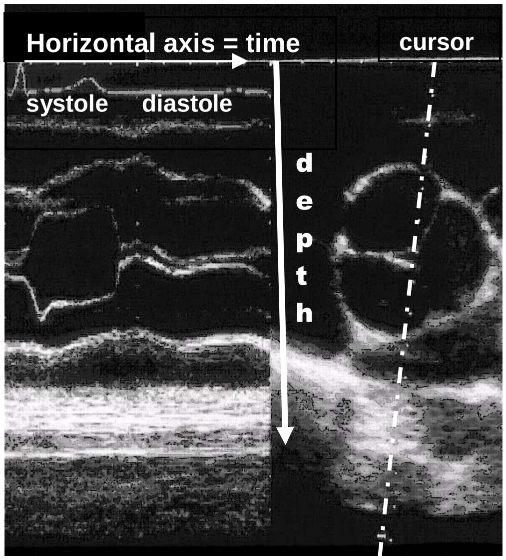
Grayscale imaging is dependent upon the dynamic range of the equipment components and is reflected in the systems' overall *contrast resolution* as was discussed earlier. The advantage of this type of imaging is that changes in tissue compliance or *'stiffness'* can be reflected in the image through contrast resolution and is usually the first indication of disease. As the tissue becomes more or less stiff it may indicate disease and is distinguishable from normal tissue.

An example is when an adenoma develops necrosis which would tend to have a more cystic or hypoechoic appearance than the rest of the lesion. Or, as in the image above, it may indicate the development of a small cyst that is seen as being anechoic in the midst of surrounding tissue which has a normal texture otherwise.

Subtle changes in the amplitude of the returning echo indicate a change in tissue compliance but if the grayscale is unable to show a distinction in gray shades, the information is lost because each pixel will be represented as the same shade of gray. The better the system can graduate the scale of shades of gray and thus separate subtle changes in tissue compliance the earlier it can detect disease. This *"tissue characterization"* by grayscale ultrasound is a major advantage of the B-Mode display.

M-Mode:

M-Mode or ***motion*** mode may also be referred to as TM or time-motion mode or PM mode (position mode). A single scan line (cursor) displays the motion of the B-mode structures relative to the transducer with respect to time on the M-mode display. The horizontal axis represents time and the vertical axis represents depth in tissue.



M-mode of aortic valve

Section 6:

IMAGES, STORAGE, and DISPLAY

SECTION 6: IMAGES, STORAGE, and DISPLAY

Objectives

Upon completion of this module, you should be able to:

- Recognize the role of the scan converter
- Outline the various steps in the scan version process
- Differentiate the types of scan converters (digital versus analog)
- Identify the various types of display devices
- Recall the differences between pre and post-processing
- State the various processes associated with pre and post-processing.
- Differentiate persistence, frame averaging, and other functions associated with pre and post-processing
- Identify the various types of recording/archiving devices and techniques

IMAGES, STORAGE and DISPLAY

ROLE OF SCAN CONVERTER

After the reflected signal goes through the various stages of the receiver, the echo information is stored in memory for the final display on the monitor. The image processor performs several functions including scan conversion, preprocessing, storing image frames, and post-processing.

Image Storage

The storage of the echo information is a function that is performed by the scan converter. The scan conversion process is done in a fraction of a second and results in one scan or image frame. Multiple frames are produced when the scan conversion process is performed repeatedly per second. The frames that are produced are stored into memory and then placed on the screen for viewing. The production and display of these frames is referred to as the real-time display. Real-time imaging refers to the whole scan conversion process. The scan converter also allows for freeze frame and image manipulation. There are two types of scan converters: analog and digital.

Analog scan converters store electrical charges. The greater the stored charge, the greater the amplitude of the echo. The instability of the analog scan converter causes the image to deteriorate with time, which is a serious limitation. As a result, analog converters have been replaced with digital scan converters.

In addition to signal integrity **digital** scan converters offer faster processing of images largely because they can do several tasks simultaneously often referred to as multi-tasking. Because the raw data is digitized it can be shared for parallel processing and quad signal processing without amplifying and splitting the signal each time. Therefore, the overall processing is faster and the original signal data is preserved without amplification or manipulation which are two of the best advantages of digital versus analog scan conversion.

Digital scan converters digitize the echo signals based on binary numbers. With a binary system there are only two numbers, one and zero, on or off.

DIGITAL DEVICES

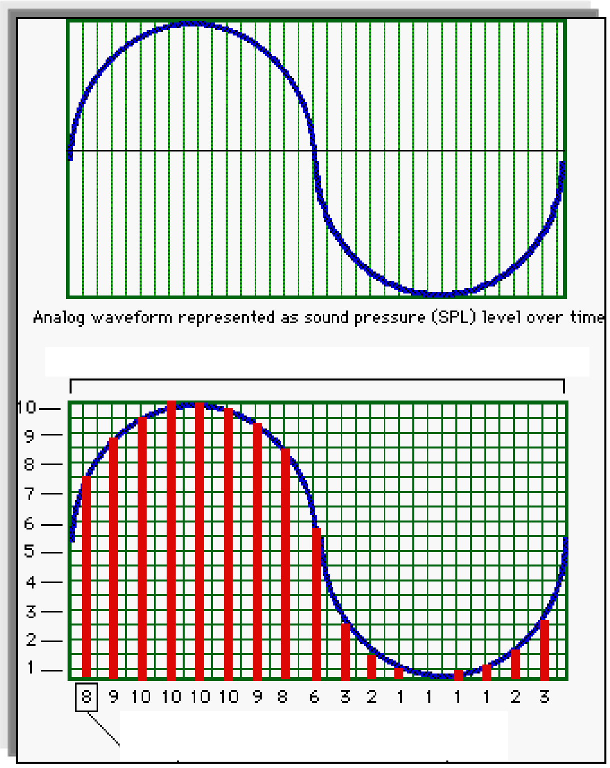
Binary System

Analog to digital conversion depends upon a simple digital system to encode the image information. The binary system provides a basic unit of stable electronic circuit which is called a ***bit.*** It works on the principle of having only two states, either high or low; or on or off. A bit is a binary digit and a ***byte*** is a group of adjacent bits. The combination of bits and bytes can create a matrix for digital image memory and display.

Steps in Processing Echo Information

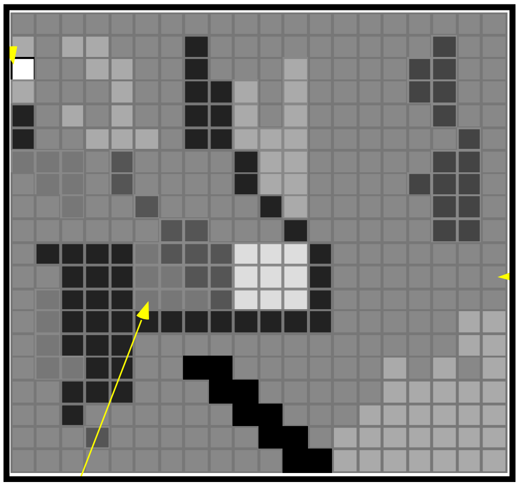
ANALOG TO DIGITAL SCAN CONVERTER

As the signals leave the receiver, they are in an analog format. **Since the digital scan converter must have a digital format, each electrical signal is changed in the analog to digital converter (ADC) to a binary number before it is placed or stored in digital memory. Essentially, converts images into numbers.**



Analog to digital (ADC)

The information is then stored in a matrix, usually 256 x 512 or 512 x 512.



Example of an image matrix

DIGITAL MEMORY

The memory resolution, which is based on the number of bits in the memory bit depth, determines how many shades of gray a system may have. As previously stated, a **bit** is a binary digit and a **byte** is a group of adjacent bits, usually eight. A group of eight bits is called **a byte**. Therefore, a byte is a combination of eight 0's and 1's.

The key to understanding this process is to recognize that these binary numbers are base 2. So, if an eight bit deep number is generated to represent a single pixel it would look like 10011001. Using base two the number can then be "decoded" by writing it thus from left to right:

$$1x2^7 + 0x2^6 + 0x2^5 + 1x2^4 + 1x2^3 + 0x2^2 + 0x2^1 + 1x2^0$$

Next, by raising 2 for each bit value to the power indicated the decimal equivalent number can be determined.

$$1x128 + 0x64 + 0x32 + 1x16 + 1x8 + 0x4 + 0x2 + 1x1$$

or

$$128 + 0 + 0 + 16 + 8 + 0 + 0 + 1 = 153$$

Thus if this were the code for pixel shade of gray from 0 - 256 it's assignment would be 153.

Thankfully the operator of the equipment does not have to do these calculations; they are done automatically. It is helpful to understand how the digital process utilizes binary numbers to encode image processing information.

Contrast Resolution

The ability of a gray scale display to differentiate echoes that have slightly different intensities is referred to as contrast resolution. Contrast resolution is dependent on the number of bits per pixel in the image memory.

The capacity of a digital memory may determine the system's contrast resolution. Bistable imaging, which is black and white, is the result of single matrix elements, which are able to store only one digit per location.

Section 7:

HEMODYNAMICS, DOPPLER, COLOR FLOW, and COLOR POWER IMAGING

SECTION 7: HEMODYNAMICS, DOPPLER, COLOR FLOW, and COLOR POWER IMAGING

Objectives

Upon completion of this module, you should be able to:

- Define hemodynamics
- Recognize the effects of viscosity, friction, and inertia associated with hemodynamic flow
- Differentiate steady verses pulsatile flow
- State the differences between laminar and turbulent flow
- Recognize the effects of stenosis on the characteristics of blood flow
- Recognize venous flow, hydrostatic pressure, and the pressure/volume relationship
- State the effects of respiration on venous flow
- Apply Doppler principles and the factors that affect flow
- List the differences between continuous wave and pulsed wave Doppler
- Recognize the advantages and disadvantages of both types of Doppler
- Recognize the advantages and limitations of color flow imaging
- Identify the instrumentation used to produce color flow imaging
- Define color power Doppler and explain its advantages and limitations

HEMODYNAMICS, DOPPLER, COLOR FLOW, and COLOR POWER IMAGING

HEMODYNAMICS

Hemodynamics is defined by Webster as *1) a branch of physiology that deals with the circulation of blood 2) the forces or mechanisms involved in circulation (540).* The Doppler evaluation of blood flow requires an understanding of blood characteristics and the factors contributing to flow through vessels in steady and pulsatile states.

Energy Gradient

In order for blood (or any fluid) to flow there must be a driving force or pressure behind blood flow. The driving forces in the circulatory system are the heart and gravity.

If the pressure at both ends of a tube or vessel is equal, no blood flow will occur. Blood flow occurs due to the difference in pressure at one point within the vessel as compared with another and is referred to as an **energy gradient or pressure gradient.**

Blood flows from regions of high pressure to regions of low pressure. A similar response is seen with a temperature gradient. For example, a temperature gradient between two adjacent rooms is a difference in temperature. If one room is 32 degrees and the other is 42 degrees, there is a gradient of 10 degrees. Leave the door closed and the gradient remains. Open the adjoining door and there is a flow of thermal energy between the two rooms. The size of the door opening relative to the size of the room will determine the time it takes for both rooms to reach the same temperature.

Pressure gradient = flow X resistance

Pressure gradient increases when flow increases and resistance increases.

Flow increases when pressure increases and resistance decreases.

Blood Flow Dynamics – Effects of viscosity, friction and inertia

The factors affecting the blood flow within the body are:

- density of the blood
- velocity of flow
- size of the vessel the blood travels through
- Inertia – what provides thrust

Inertia: objects in motion tend to stay in motion – Issac Newton. These forces will occur as pressure to displace or move the blood throughout the body. The relationship between pressure and blood flow will be discussed later but first there are other factors that affect blood flow dynamics. **Inertial energy losses can occur during phasic flow, pulsatile flow, and changes at a stenosis.**

Viscosity loss is determined by hematocrit. is the resistance to flow and is directly related to the density (thickness) of blood. Blood is comprised of plasma, erythrocytes (RBC), leukocytes (WBC), and platelets. Red blood cells comprise about 99 % of the cells in the circulation. The density is its mass per unit volume (g/mL) with blood having slightly greater density than water. The greater the mass (density), the greater resistance to flow acceleration. The hematocrit is the ratio of the volume of red blood cells to the total volume of blood.

The number of cells traveling through the vessel also changes the flow of blood. Increases in hematocrit levels (number of red blood cells) results in the blood becoming more viscous and dense. An

Section 8:

ARTIFACTS

SECTION 8: ARTIFACTS

Objectives

Upon completion of this module, you should be able to:

- State the definition of an artifact
- Identify the various types of artifacts
- Recall the mechanisms behind the production of the various artifacts
- Identify the characteristics of the various artifacts
- Recognize the effects of artifacts on measurements

ARTIFACTS

DEFINITION of ARTIFACTS

An imaging artifact is anything that does not correctly represent a structure. Some artifacts can result from improper scanning techniques or operation of system controls, and other artifacts are inherent to the ultrasound system, physics of ultrasound or imaging methods.

Several assumptions are made with the design of ultrasound equipment and the subsequent signal processing. The basic assumptions include:

1. Sound travels in a straight line.
2. The speed of sound in soft tissue is constant, around 1540 m/s.
3. Sound travels directly to a reflector and back.
4. The detected echo originated from the last pulse generated.
5. The amplitude of the returning echoes is directly related to the reflectors scattering through.

ARTIFACT RECOGNITION in PERFORMING and INTERPRETING EXAMINATIONS

To avoid diagnostic errors the sonographer and sonologist must be familiar with commonly seen image and Doppler artifacts.

The artifacts of Sonography fit into one of 4 categories:

Not Real
Echoes that do not represent actual interfaces such as mirror image which will be discussed in detail later.

Missing Echoes
This would include anatomy hidden by distal acoustic shadowing from attenuation or from refraction for instance.

Misrepresented Interface Location
An example of an improperly located reflector would be propagation speed or lateral position errors.

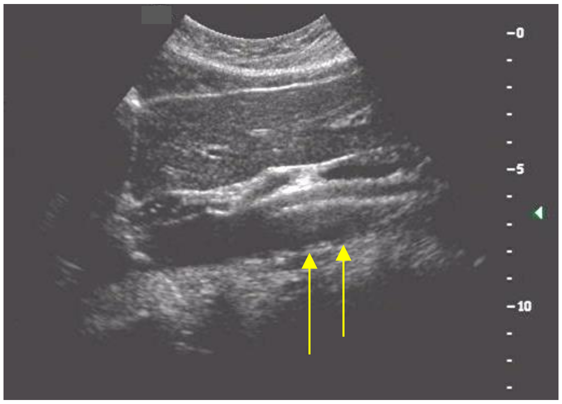
Misrepresented Interface Amplitude
This artifact would include those situations when there is improper brightness, shape or size registration of an interface or reflector.

More details will be provided about each of these types of artifacts and their common characteristics.

ARTIFACTS ASSOCIATED with RESOLUTION and PROPAGATION

Acoustic Speckle
Speckle is caused by the interference of energy from scatterers which are too small to be resolved by the ultrasound system. This causes the image to exhibit a grainy appearance which reduces the contrast resolution.

Beam Section or Slice-thickness Artifact
A beam section or slice thickness artifact occurs when a portion of the sound beam interacts with a fluid-filled structure and an adjacent echo producing a structure that is off axis. **A target that is smaller than the ultrasound image slice is averaged within the slice volume and disappears.**



Slice-thickness artifact

GULFCOAST
ULTRASOUND
INSTITUTE INC

Section 9:

QUALITY ASSURANCE of ULTRASOUND INSTRUMENTS

SECTION 9: QUALITY ASSURANCE of ULTRASOUND INSTRUMENTS

Objectives

Upon completion of this module, you should be able to:

- Outline the need for a quality assurance program
- Compare the various methods used to evaluate the performance of ultrasound instruments
- Recognize the differences between test objects and tissue phantoms
- Identify the parameters that are evaluated with tissue phantoms
- Recognize the parameters that are evaluated with test objects
- Identify the materials used in the various phantoms and test objects to obtain measurements
- Recognize the need for preventative maintenance and record keeping
- Differentiate statistical indices and state their importance

QUALITY ASSURANCE OF ULTRASOUND INSTRUMENTS

GENERAL CONCEPTS REGARDING the NEED for and NATURE of a QA PROGRAM

As in all areas of medicine, diagnostic imaging is required to develop and routinely conduct checks to ensure the quality of patient care and management. There are several general reasons or goals to be achieved with a QA program including:

- Minimize equipment downtime
- Detect small gradual changes
- Ensure and document proper equipment performance

Quality Assurance

QA and quality control are two of the more common programs. Quality assurance programs focus on the patient. Quality assurance programs evaluate scheduling, accuracy of interpretation, distribution of reports, and how the procedure impacts patient care.

Quality Control

Quality control is oriented to focus on the instrumentation and equipment. Quality control has three distinct parts:

1. Assessment of diagnostic accuracy
2. Maintenance of imaging apparatus
3. Periodic equipment performance

METHODS for EVALUATING INSTRUMENT PERFORMANCE

Transducers, hard copy image, image processor, and the console should be monitored on a regular basis. The devices used are divided into groups:

- Devices that test imaging performance
- Devices that test the measurement of acoustic output.

Tissue Equivalent phantoms

Tissue-equivalent phantoms and test objects are the two types of tools that test the performance of ultrasound imaging equipment. Tissue-equivalent phantoms have characteristics that mimic those of real soft tissue.

Test Object Phantoms

Test objects do not have the characteristics of soft tissue but are used to provide measurements of instrument performance. Recently, some devices have combined elements of both the test object and tissue-equivalent phantom. All equipment test procedures and results need to be recorded in a log for future reference. Performance measurement tests can be done by the operator or service representative. All of the following are measured for quality control:

- Detail Resolution
- Contrast Resolution
- Penetration
- Dynamic Range
- Compensation Operation
- Range (depth or distance) accuracy

PARAMETERS TO BE EVALUATED

Test Objects

Currently, there are many commercially available test objects. One of the first test objects that was used was the AIUM test object. The AIUM test object is a five-sided plastic box with one corner beveled. Inside are 75 mm stainless steel plastic pins that form a 100 x 100 mm grid. The test object is filled with a fluid mixture made to have the same propagation speed as that of soft tissue.

The rods are arranged into five groups labeled A through E.

DEPTH CALIBRATION – Group A

There are 6 rods that are 20 mm apart in a vertical row. These rods evaluate depth calibration, vertical linearity, and gain.

GULFCOAST ULTRASOUND INSTITUTE INC

Section 10:

BIOEFFECTS and SAFETY

SECTION 10: BIOEFFECTS and SAFETY

Objectives

Upon completion of this module, you should be able to:

- Differentiate the various acoustic output quantities
- Identify the methods used to determine power
- Recognize the various intensities associated with diagnostic ultrasound
- Recall the relationship of intensity and power to various operating modes
- Recognize the acoustic output labeling standard associated with thermal and mechanical index
- State the ALARA principle and its implementation
- Apply the methods needed to reduce acoustic exposure
- Recognize the production of biologic effects
- Differentiate cavitation and thermal mechanisms
- Identify the use of various experimental studies regarding biological effects
- Identify the guidelines and regulations set forth by the AIUM, NEMA, and FDA
- Recognize the various electrical and mechanical hazards associated with diagnostic imaging

BIOEFFECTS AND SAFETY

At the time this manual was printed, no known tissue damage on patients has been documented by the use of diagnostic medical ultrasound. Biological effects are the effects a sound wave and its associated energy has on biologic tissue that it has passed through.

Dosimetric effects are very difficult to obtain and are usually confined to research on very sophisticated labs. In order to obtain dosimetric measurements one of the following is required:

1. calibrated transducer
2. hydrophone
3. radiation microbalance

In practical terms, it is useful to measure the power levels produced by diagnostic ultrasound instruments. While the complete characteristics of dosimetry have not been identified, a clear definition does exist: **Dosimetry** is the science of measuring and identifying ultrasound beam characteristics. High intensities would be an example of this. Attenuation makes it difficult to study the intensities in soft tissue.

ACOUSTIC OUTPUT QUANTITIES

Measurements of Pressure

Variations of spatial distribution of the ultrasonic power are described by specifying the intensity at different points in the beam. This is used to measure the shape of the ultrasound beam and the acoustic pressure distributions within the beam. Once the absolute acoustical pressure is measured, the hydrophone can calculate the absolute intensities at various points. Pressure units are given in pascals (Pa) or megapascals (MPa). A pressure waveform analyzed by a hydrophone is the signal produced by the pulsed transducer that is detected in a tank of water when the hydrophone is positioned under a sound beam. The hydrophone can detect the peak positive or peak compressional, as well as the peak negative or peak rarefactional pressures.

Measurement of Power

Measurement of ultrasound output is generally performed either in research or very sophisticated labs. **The units of measure for power is watts. Beam area is expressed in cm2. Intensity is measured in mW/cm2.** The equipment that measures output comes in several types including:

1. Crystals – Evaluates the shape and strength of the beam by exposing cholesteric liquid crystals to different intensities causing them to change colors. The color and shape of the crystal allows us to evaluate the beam.

2. Hydrophone – Quantitates amplitude, period, pulse duration, and pulse repetition period. A piezoelectric crystal is attached to an oscilloscope, which displays the signals. The amplitude of the received signal is proportional to the pressure amplitude.

3. Radiation force – Measures the SATA intensity or the SPTA intensity.

4. Calorimeter – Looks at the total power of the beam. The transducer converts the energy into heat.

5. Acoustic optics – Quantitation of pulse repetition period, amplitude period, and pulse duration. Beam profile can be measured by Schileren using the same method. Both sound, light waves and the reaction to each other are evaluated.

6. Thermocouple – Specific points are measured for the intensity. The device is in the material, and as the ultrasound is turned into heat by the process of absorption, the temperature change is measured. **Measures temperature rise at a specific location.**

CME Certificate Instructions

To take the quiz for this program and receive CME credit:

1. Point your browser to https://www.gcus.com

2. Log into your account.

3. Select "My Activities" from the top menu, find this product **(PAU-OL1-SPI4)**, and click the “CME QUIZ/CREDIT” button to access your Pre-Paid Quiz, or purchase CME Quiz/Credit at this point.

4. Take the quiz.

5. After passing the quiz with a 70% or higher, fill out a short survey to continue.

6. A certificate will automatically be generated for you to print out.

Questions? Call (727) 363-4500   Monday-Friday 8:30am-5:00pm EST

ULTRA P.A.S.S.

Sonography Principles and Instrumentation Registry Review Workbook

6th Edition

PAU-OL1-SPI4

GULFCOAST ULTRASOUND INSTITUTE INC

www.gcus.com

Published by:
Gulfcoast Ultrasound Institute, Inc.
111 2nd Avenue NE, Suite 800
St. Petersburg, FL 33701
www.gcus.com
727-363-4500

ISBN# 978-1-950973-96-5

GUI Item#: PAU-OL1-SPI4
Date of Original Release: 6/20/2025
Reviewed by: Gulfcoast Ultrasound Insitute CME Committee
This edition valid for credit through: 6/20/2028