1-1 Unrelated

- Directly Related
- Inversely related
- Unrelated

1-2

Giga	9	G	Giga	nano
Mega	6	M	Mega	micro
kilo	3	k	kilo	mili
hecto	2	h	hecto	centi
deca	1	da	deca	deci
deci	-1	d		
centi	-2	c		
mili	-3	m		
micro	-6	u		
nano	-9	n		

G	giga	10^9	1 000 000 000	billion
M	mega	10^6	1 000 000	million
k	kilo	10^3	1 000	thousand
h	hecto*	10^2	100	hundred
da	deka*	10^1	10	ten
		10^0	1	one
d	deci*	10^{-1}	0.1	tenth
c	centi*	10^{-2}	0.01	hundredth
m	milli	10^{-3}	0.001	thousandth
µ	micro	10^{-6}	0.000 001	millionth
n	nano	10^{-9}	0.000 000 001	billionth

2-1 – Sound

Sound – A ***Mechanical Longitudinal*** Wave In Which ***Back And Forth Molecular Motion*** Is ***Parallel To The Direction Of Flow***.

- Transverse Wave – Particle motion is in the Direction PERPENDICULAR to the direction of flow - Not Ultrasound

Acoustic propagation – effects of tissue on sound
Biologic effects – effects of sound on tissue

Infrasound	0 – 20 Hz
Audible sound	20 Hz – 20 kHz
Ultrasound	20 kHz and above

ALL WAVES TRAVEL AT THE SAME SPEED THROUGH HE SAME MEDIUM. Speed is medium dependant.

Sound – can not travel in a vacuum (only heat, light and television can)
Sound - Must travel through a medium (heat, light and television do not require medium)
Sound - Must have molecules to compress and rarefied

Interference - identical location of medium were multiple sound beams arrive at exactly the same time.

Constructive inference – in- Phase waves - The Formation of a single wave of GREATER amplitude of either two waves.

Destructive – Out-Of-Phase Waves – The Formation of a single wave of LESSER amplitude of either two waves.

2-2 Acoustic variables

- Pressure – Pascals or atmosphere atm or mmHg or lb/in^2 - concentration force in an area
- **Pressure = force / area applied**
- Density – kg/cm^3 - concentration of mass in a volume
- Distance – Particle motion - cm – measurement of Particle motion

2-3 Acoustic parameters

Parameter	Definition	Units	Determined	Adjustable	Values
Period	Time of one cycle	us	Sound Source	No – set to transducer	.0000001 - .0000005 us
Directly related		Inversely related		Unrelated	
Pulse Duration Wavelength					
Frequency	# cycles in time period	Hz, per day, Cycles/sec,	Sound Source	No - set to transducer	2 MHz – 10 MHz
Directly related		Inversely related		Unrelated	
Absorption - Scattering Attenuation - Focal depth Image quality		Period - Pulse Duration Spatial Pulse Length Wavelength - Penetration PZT thickness		Speed of Sound - PRP Intensity - PRF Power	
Amplitude	Bigness of a wave	Pascals, Amt, kg/cm3, cm	Sound Source	Yes	1Mpas – 3Mpas
Directly related		Inversely related		Unrelated	
Intensity Power		Attenuation			
Power	Rate of energy transfer	Watts	Sound Source	Yes	.004 - .090 watts
Power = Amps2					
Directly related		Inversely related		Unrelated	
		Attenuation		Pulse	
Intensity	Concentration of energy	W/cm^2	Sound Source (BUT AFTER TRAVELS THROUGH THE BODY= BOTH)	Yes	.01 – 300 w/cm2
Intensity = Amps2			**Intensity = power / area**		
Directly related		Inversely related		Unrelated	
		Attenuation		Wavelength	
Wavelength	Length of one cycle	mm	Both source and medium	No	.15 - .8 mm
Wavelength = 1.54 or speed of sound / F			**Shorter Wavelength = Higher Quality imaging** **High F Transducers = Short Wavelength**		
Directly related		Inversely related		Unrelated	
		Frequency			
Propagation Speed	Distance and time a wave travels through a medium	m/s or mm/us or miles per hour, mm/msec, km/sec, inches per year	Medium	No	1540 m/s 154000 cm/s 1.54 mm/us 1/54 km/s 1 mile per second
Propagation speed = F * Wavelength					
Directly related		Inversely related		Unrelated	
Stiffness		Density		Attenuation	

Propagation speed chart — Attenuation chart

Medium	**m/s**	**1.54 mm/us**	Water	Lowest
Air	330	15.40 cm/	Blood	
Lung	500	154 d/		
Fat	1450	**1540 m/s**	Fat	
Water	1480			
Soft tissue (average)	1540		Soft tissue	
Liver - Blood	1560			
Muscle	1600		Muscle	
Tendon	1700			
Bone	3500		Bone	
Metals	2000 – 7000		Air	Highest

3-1

Stiffness – Ability of an object to resist compression a pin pong ball is stiff a marshmallow is not.

- Elasticity and Compressibility – are opposites of stiffness.
- NON STIFF media are described as Elastic or compressible.

Density - relative weight of different material, steel is dense aluminum is not MASS.

Pulsed Ultrasound

Parameter	Definition	Units	Determined	Adjustable	Values
Pulse Duration	Time of one transmitted PULSE	us	Sound Source – Transducer designed	No – remain constant no matter of depth	.3 –2 us 2 – 4 pulses
PD = # Cycles * period		**PD = # cycles / frequency**		**Shorter pulses = quality image * high F transducer**	
Directly related		Inversely related		Unrelated	
Cycle period Number Of Cycles Period Pulse Length Duty Factor		Bandwidth Frequency		Temporal resolution	
Spatial Pulse Length	Distance the pulse occupies Transmit only	Mm	Both - Sound Source & Medium–	No – remain constant no matter of depth	
SPL = # cycles * wavelength		Transducer designed		**Shorter pulses = quality image * high F transducer**	
Directly related		Inversely related		Unrelated	
Number Of Cycles Wavelength Q-Factor		Frequency			
Pulse Repetition Period	Time from the start of one pulse to the start of the next trans & listen	us	Sound Source	Yes – Depth Deeper depth longer PRP – depth changes the listening time only	100 us – 1 ms
PRP = depth * 13 us/cm					
Directly related		Inversely related		Unrelated	
Image Depth		PRF		Frequency Period	
Pulse Repetition Frequency	Number of pulses transmitted during transitions	Hz	Sound Source	Yes – Depth Deeper depth lower PRF	
PRF = 77,000/ image depth			**PRF = Lines per frame * frame rate**		
Directly related		Inversely related		Unrelated	
Temporal resolution Increased Frame rate		Pulse Repetition Period Decrease Depth		Frequency	
Duty Factor	% or Fraction of time the system is transmitting over the listening time	% or fraction	Sound Source	Yes – Depth – higher factor at shallow – lower at deeper	Minimum value is 0- no transmitted signal and max value is 100 when CW is on.
Duty Factor = Pulse Duration / PRP *100					
Directly related		Inversely related		Unrelated	
		Depth			

5-1 Intensities – units W/cm²

Spatial-distance space	SATP- Spatial Average Temporal Peak
Peak-max value	SATA- Lowest value
Average-middle value	**SPTA-Tissue heating causing Bio effects**
Emporial-time pulses and receives	SAPA
Pulsed-time transmitted	SPPA
SPTP – Highest value	

Spatial – refers to location in space.

- Dependant on the location of the measurement
- Beam uniformity coefficient or SP/SA factor – describes the spatial distribution of acoustic energy of a beam in space. This value **= unit less** and is always valued between 0 – 1 or 100%.

- Duty factor (cycle) – relationship of beam intensity with time**, is unit less** and is valued between 0 – 1 or 100%.

- For CW the beam is always on so the pulse average and temporial average **(PATA TPTA)** intensities are the same. **Thus SPTA = SPPA and SATA = SAPA**.

- Rank of intensities from highest to smallest is **SPTP - I_M – SPPA – SPTA – SATA.**

6-1 Sound and Media

Attenuation - The weakening of sound as it travels/propagates. In US we are interested in the degree of weakening or the extent of amplification.

Logarithms – 10 based rating of numbers the number of times ten must be multiplied by 10 to achieve the original number
1,000 is log 3 – 10,000 is log 4 and so on

Decibel notation – DN is logarithmic reports relative change. **Logarithmic and relative Measure in RATIO – measures the relative strength.**

Increase amount	Multiples of amplification	Decreased amount	Multiples of amplification
3 dB	2x	- 3 dB	1/2x
6 dB	4x	- 6 dB	1/4x
9 dB	8x	- 9 dB	1/8x
10 dB	10x	- 10 dB	1/10x
20 dB	100x	- 20 dB	1/100x
30 dB	1000x	- 30 dB	1/1000x

Attenuation – decrease in intensity power
Factors of attenuation: Path Length x frequency of sound

More attenuation	Less Attenuation
Larger distance	Shorter distance
Higher frequency	Lower frequency

Process, which contribute to attenuation:

- Reflection
- Scattering
- Absorption
-

Reflection: The reflection produced as sound moves for one medium to another – Acoustic Impedance is an important tissue property that influences the amount of reflection.

Specular - Smooth small surface with reflection in **one direction back to the transducer**	Diffuse Reflection or back scatter – Strike small object with a rough surface develops **many different** directional reflections **back to the transducer**
Organized	Disorganized

Scattering

Rayleigh – scattering that occurs when structure dimension are much smaller than the beams wavelength redirects sound **EQUALLY in all direction** (like drop of water in lake)	Scattering is the RANDOM **in all direction** - interfaces with small object, less than the size of the wavelength. Lung tissue cause scattering because of the air.
Organized	**Disorganized**
Rayleigh = F^4	

6-2

Absorption - Accurse when US energy is converted to heat.

Attenuation coefficient – dB of attenuation in 1 cm dB/cm

Total attenuation = Attn. Coef * distance	**Attenuation Coefficient = F/2**

Attenuation chart

Water	Lowest
Blood	
Fat	
Soft tissue	
Muscle	
Bone	
Air	Highest

Half Value Layer Thickness – (units) - CM – distance sound travels that will reduce intensity in half .25 – 1 cm

- Dependant on **Medium and Frequency** of sound

Thin Half Value	**Thick Half Value**
High Frequency	Low Frequency
Media w/ high attenuation rate	Medium with Low attenuation rate

6-3 Impedance – acoustic resistance to sound (rayls)

- Determined by - Medium values – 1.25 – 1.75 Mrayls

Impedance = density * propagation speed in a medium

6-4 Incidences - Acute (Oblique) < 90^o Right = 90^o Obtuse (Oblique) - > 90^o

- Acute and Obtuse angles also are called **oblique**

Normal incidences – (orthogonal, perpendicular, right Angle, 90 degree) beam strikes boundary at exactly 90^o

Oblique incidences – beam strikes boundary at any other angle but 90^o

Incidence intensity – Intensity right before sound wave strikes medium **=IRC + ITC**
Reflected intensity - Intensity of the portion of the beam that is reflected back to the transducer

WITH Normal incidences

Transmitted Intensity - Intensity of the portion of the beam that continues forward

Intensity reflected coefficient (IRC) - % of intensity that **bounces back** when the sound beam passes from one medium to another. < 1% (when both boundaries are soft tissue). - As the impedance of the two boundaries is greater in impedance (tissue/bone) the IRC goes UP 1% = 100%

Intensity Transmission coefficient (ITC) – The % of intensity that **passes forward** when the sound beam passes from one medium to another > 99%(when both boundaries are soft tissue). As the impedance of the two boundaries is greater in impedance (tissue/bone) the ITC goes DOWN 1% = 100%

- Normal Incidence – same impedance = no reflection
- Normal Incidence – slightly different impedance = small reflection
- Normal Incidence – Large difference in impedance = Large reflection

ITC % =Transmitted Intensity / incident intensity * 100

WITH Oblique incidences

- The angle of incidence = the angle of reflection

6-4 Refraction - The change in direction of wave propagation – the bending of sound

- **Only occurs on OBLIQUE incidences & when propagation speeds are different in two mediums**

Snell's Law – The physics of refraction

Speeds	Angle of transmission
Speed 2 = Speed 1	No refraction, transmission angle = incident angle
Speed 2 > Speed 1	Transmission angle > incident angle
Speed 2 < Speed 1	Transmission angle < incident angle

7-1 Range Equations

Time-of-Flight – go return time – depth = 1.54 or PS * go return time/ 2

Time of Flight	Reflector depth	Total Travel Distance
13 us	1 cm	2 cm
26 us	2 cm	4 cm
39 us	3 cm	6 cm
52 us	4 cm	8 cm

8-1 Axial Resolution – (mm) (Sound Source) (no-adj) Ability to display/measure 2 separate objects when lying parallel to each other – the minimum distance you can measure two object in a longitudinal plan. (typical - value .01 – 1 mm same as SPL)

- Determined by – Spatial pulse length – which is determined by both source and medium THUS – Axial resolution remains constant no matter of depth

- Other names –Longitudinal Resolution – Range Resolution – Radial Resolution – Depth Resolution

- Lower value gives better resolution.
  - **AXIAL Resolution = .77* number of pulses / f**
  - **AXIAL Resolution = Spatial Pulse length / 2**
  - **SPL = # of cycles *wavelength**

Directly related to - (Low numerical values) – better image	Indirectly related to
Short SPL	
Short Pulse duration - Less ringing & higher F	
Fewer cycles per pulse- Less ringing	
	High frequency (short wavelength - pulse)
More accurate image –lower value	

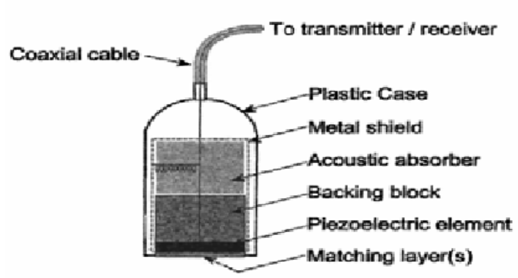
9-1 Transducers - CHANGES ONE FORM OF ENERGY IN ANOTHER FORM OF ENERGY

9-2 Continuous Wave Transducers – PEDOFF Probe –
- Two Crystals – one send one receives – shape semi circle
- No backing material
- Narrow bandwidth
- High Q-factor
- High sensitivity
- Frequency of Pedoff is dictated by the electrical signal sent from the US system not the crystal.

9-3 Duplex Imaging Transducers

Piezoelectric effect: pressure. applied to a crystal; electrical voltage appears on surface of crystal

Reverse Piezoelectric effect: electrical voltage applied to crystal~ pressure waves or sound waves generated.
Major component is crystal – ceramic LEAD ZERCONATE TITANATE (PZT)



- Case – Outer shell – prevents electrical shock
- Electric shield – Lining inside of case –prevents noise
- Acoustic insulator – Cork / Rubber – insolates components from Case Prevents vibration in case
- PZT – Active Element – shaped like a disk or coin - ½ wavelength
  - Frequency of a probe is determined by the propagation speed of the crystal and the thickness of the crystal
  - **Thin crystal & high Propagation speed – high frequency**
  -
- Wire – one for each PZT
- Matching layer – In front of PZT Transmits sound - ¼ Wavelength think increases sound transfer & protects active element
- Backing Material – Reduces Ringing – epoxy resin – dampens pulse - Decreases Sensitivity
  - Wide Bandwidth
  - Low Quality Factor
  - Reduces Q-Factor
  - Decreases Spatial Pulse length
  - Shortens pulse duration & length
  - Improves axial resolution

Component	Thickness
Active Element	½ Wavelength think
Matching Layer	¼ Wavelength think

Polarization process:
CURRY POINT - Heat crystal to curry point of 365 degree CELSIUS
Slowly cool to room temp
To maintain polarization, must not DROP or HEAT

STERILIZED – high heat autoclave BAD
Disinfectant – low temp chemical cleaning –PREFERRED OPTION

Imaging Transducer	
Pulses w/ short duration and length	Wide Bandwidth
Uses backing material to limit ringing	Low Q Factor
Reduces Sensitivity	Improved Axial Resolution

Q-Factor – unit less number that is related to ***inversely bandwidth***
- **Q-Factor = Main Frequency/Bandwidth**
- Short pulse – low Q-Factor (PREFERRED)
- Long Pulse – high Q-Factor

Pulsed wave Imaging probe

Characteristics of **HIGH** Frequency PW imaging transducers	Characteristics of **LOW** Frequency PW imaging transducers
Thin PZT crystals	**Thicker** PZT crystals
PZT with **high** speed	PZT with **Low** speed

10-1 Sound Beams
Anatomy of the sound beam
- Focus – Narrowest beam diameter – ½ width if beam
- Near Zone – Fresnet – Distance from transducer to Focus
- Focal Length – Near zone length
- Far Zone – Frauhofer – focus point to farthest beam
- Focal Zone – equally spaced region on either side of focus

Effects of Focal Zone

Shallow Focus	Deep Focus
Small diameter PZT	Large diameter PZT
Low Frequency	High Frequency

Focal Depth = diameter of PZT^2 / 4 x wavelength

10-2 Sound beam Divergence - point / size diameter at end of far Zone

- Two factors that determine beam divergence
  - Transducer diameter
  - Speed of the sound

Less Beam Divergence	More Beam Divergence
Larger diameter transducer	Smaller diameter transducer
High Frequency	Low Frequency

10-2-1 Spherical Waves – Waves (V-Shape) produced by very small tiny pieces of PZT

- V-shaped waves known as spherical waves or diffraction patterns or **Huygens wavelets**
- **Huygens Principles - Many small v shaped waves combined by *INTERFERENCES* to form the standard hour glass wave form**

- 10-3 Lateral Resolution – CHANGES WITH DEPTH - Identifies two structures that are side-by-side and perpendicular to the sound beam
- Lower Lateral Resolution is best at the focus or narrowest part of the beam
- Determined by - width of sound beam – narrower beams have better resolution
- units – mm, cm, distance
- Best at focus and good within the focus zone
- The minimum distance two objects side by side can be measured and viewed as two objects.
- Also called – Angular resolution, transverse resolution or azimuthal resolution
- High Frequency transducers improve Lateral resolution because high Frequency pulses diverge less (narrower) in the far field than low frequency

Lateral resolution = Beam diameter
Minimum lateral resolution = ½ PZT diameter = Focus

- Degrades with multi focus zones
- Dynamic aperture – (Variable Aperture, changing the aperture) – Array transducer only – changes the number of crystals used thus making a smaller or larger beam to improve lateral resolution at deeper depths
- NOT RELATED TO: Pulse duration

10-4 Focusing = improves lateral resolution by concentrating the sound energy into a narrower beam.

Three types of focusing

- External Focusing – With the use of a lens
- Internal focusing – With the use of a curved active element
- Phased array focusing – With the use of electronic ultrasound system
  - (Phased array – means adjustable or multi focusing)

Focusing techniques

Method	Name	Type
Lens	External	**Fixed**, conventional or

		mechanical
Curved active element	Internal	**Fixed**, conventional or mechanical
Electronic	Phased Array	**Adjustable Variable and multi- focusing**

Effects of focusing – alteration to the beam

- Beam diameter in near field and focal zone is reduces
- Focal depth is shallower
- Beam diameter in the far zone increases
- Focal zone is smaller

Summary of Beam Features

Characteristics	**Determined By**
Frequency – CW	Electrical Frequency from US System
Frequency – PW	Thickness of ceramic and Speed of sound in ceramic
Focal Length	Diameter of ceramic & Frequency of sound
Beam divergence	Diameter of ceramic & Frequency of sound
Lateral Resolution	Beam Width

11-1 Display mode

- A-Mode - Amplitude
- B-Mode – B-Scan - Gray scale imaging
- M-Mode – Motion mode

** Depth – time of flight horizontal

Modality	**x – axis**	**Y - axis**	**z- axis**
A- Mode	Depth	Amplitude	
B- Mode	Depth		Amplitude
M- Mode	Time	Depth	

12-1 Two Dimensional Imaging

Mechanical Transducer - Number of Crystals - 1

- Image Shape – Pie shaped Fan or Sector shaped

Beam Steer- **Fixed**, conventional or mechanical –
Beam Focusing - **Fixed**, conventional or mechanical

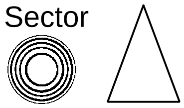
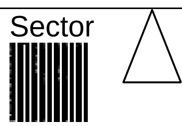
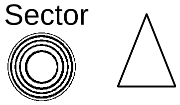
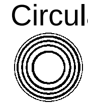
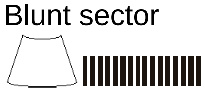
12-2 Array Transducers

Type	**Arrangement**
Linear	Elements in straight line
Annular	Elements are in a circular ring with a common center
Convex – Curved – curvilinear	Elements are arranged in a curved or bowed arch

12-3 Focusing and steering

- Steering - Electric pattern - **Sloped**
- Focusing - Electric pattern – **Curvature**
- Dynamic receive – **focusing during reception of reflected sound –** can not be used by single crystal transducer HAPPENS AUTOMATICALLY and can not be changed

- Apodization – alters electrical spike so the curvature of the voltage is higher in the center and gradually diminishes to the sides – THIS REDUCES THE SIDE AND GRATING LOBE ARTIFACT.
- Dynamic aperture – (Variable Aperture, changing the aperture) – Array transducer only – changes the number of crystals used thus making a smaller or larger beam to improve lateral resolution at deeper depths

Transducer	Image Shape	Steering	Focusing	Elements	Fires
Mechanical	Sector 	Mechanical two dimensional image built up by rotation	Fixed can not focus at multiple depths	1 rotates out like bike wheel	Element is in a circular ring with a common center
Linear Sequence Array	Rectangle 	Electronic fires in groups from different locations of the face some but not all crystals are used	Electronic Electric pulses excite elements and arrive at different patterns depending on the focus-multi focusing	120-250 side by side - **rectangular larger 1 wavelength in width**	Simultaneous in order side by side 1,2,3,4,5
Linear Phased Array	Sector 	Electronic	Electronic electric pulses excite elements and arrive at different patterns depending on the focus-multi focusing	100-300 side by side - **rectangular - ¼ to 1/2 - Wavelength think**	At All most the same time.
Annular Phased Array	Sector 	Mechanical	Electrical – Focuses all planes at all depths - multi focusing	1 Per ring – Circular 4 rings	Circular  Electric pulses excite elements arrive at each PZT at different time micro seconds apart
Convex	Blunt sector 	Electronic fires in groups from different locations of the face some but not all crystals are used <u>beams not parallel to each other</u>	Electronic pulses excite elements and arrive at different patterns depending on the focus-multi focusing <u>DYNAMIC RECEIVING FOCUSING IS USED</u>	120-250 side by side - **rectangular larger 1 wavelength in width**	Simultaneous

Vector	Trapezoid	Electronic fires in groups from different locations of the face some but not all crystals are used	Electronic Focuses all planes at all depths - multi focusing DYNAMIC RECEIVING FOCUSING IS USED	120-250 in order side by side	Simultaneous

12 – 4 Effects of Damaged PZT

Mechanical	Linear Sequence Array	Linear Phased Array	Annular Phased Array	Convex	Vector
	Top to bottom vertical band drop out	Can not be precisely determined	Horizontal band drop out	Top to bottom vertical band drop out	

<u>12-5 Slice Thickness Resolution or Elevational resolution</u>

- Resolution of above and below the plan – thickness of beam of plan

<u>12-6 Special topics</u>

- <u>Side Lobes</u> – Additional beams created outside the main sound beam in the Far Zone that do generate reflection – degrade the lateral resolution. –
    - Beams created by **single element transducers** (Mechanical)

- <u>Grated Lobes</u> – Additional beams created outside the main sound beam in the Far Zone that does generate reflection – degrade the lateral resolution. –
    - Beams created by **Array** transducers

<u>13-1 Real Time Imaging</u>

- Temporal Resolution – Accuracy in time, determined by frame rate. (Hz or per sec)
- Determining factors – (frame rate) speed of sound, depth of view, pulses per image,
    - Not effected by length of pulse
    - Effected by shallow Depth, sector angle, line density, #of focuses, pulses per scan
    - Excellent when frame rate is HIGH
- Best comes from M-mode since it is single dimension
- Color is the worst modality, color takes to many lines per frame = low frame rate.

- Frame Rate - determined by **speed's of the medium & depth of the reflector** (Hz or per sec)

- Frame Rate & T_{frame} are Reciprocals - **Frame Rate * T_{frame} = 1**
  # Line Per Frame * Frame Rate = PRF
  T_{frame} = # of Pulses *PRP

System setting that determine frame Rate:

Imaging depth –

Shallow Imaging	Deep Imaging
Short Go-return- time	Long go-return-time
Short T_{frame}	Long T_{frame}
Superior Temporial Resolution	Inferior Temporial Resolution

Number of pulses per frame

Factors Determining Number of pulses per Frame
Number of Focal Points
Sector Size
Line Density

Imaging depth and frame rate **are inversely related**

Number of Focal Points - Adjustable

Single focus	**Multi Focus**
One Pulse Per Scan	Many pulses per scam
Short T_{frame}	Long T_{frame}
High Frame Rate	Low Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution

Sector Size- Field of view - Adjustable

Single focus	**Multi Focus**
One Pulse Per Scan	Many pulses per scam
Short T_{frame}	Long T_{frame}
High Frame Rate	Low Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution

Line Density – Number of lines per sector

Low Line Density	**High Line Density**
Widely Spaced lines	Tightly Spaced lines
Fewer Pulses per frame	More Pulses per frame
Short T_{frame}	Long T_{frame}
High Frame Rate	Low Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution
Inferior Spatial Resolution	Superior Spatial Resolution

Line Density and Frame rate are **inversely related**

Summary of Temporal resolution

Better – Higher Frame Rate	**Worse – Lower Frame Rate**
Shallow Imaging	Deep Imaging
Single Focus	Multiple Focus
Narrow Sector	Wide Sectors
Low Line Density	High Line density

14-1 Pulsed Echo Instrumentation

Transducer - Transmission & Reception	Sends - Piezoelectric effect Receives - Reverse Piezoelectric
Pulser - Transmission	Excites PZT - Determines Amplitude – PRP & PRF
PRP & PRF – determines maximum depth of image PRP Low = Less listening time – Shallow Image – PRF High PRP high = More listening time – Deeper Image – PRF Low PRP & PRF are Reciprocal	
Beam former	Determines firing display pattern for Phased Array systems
Receiver	Transforms electrical energy from the Trans. Into suitable form for display.

Display	Presents data
Storage	Archives studies
Master synchronizer	Organizes proper timing and interaction of system components

14-2 Pulser – Adjustable YES – Range 0 to 500 Volts – Transducer output

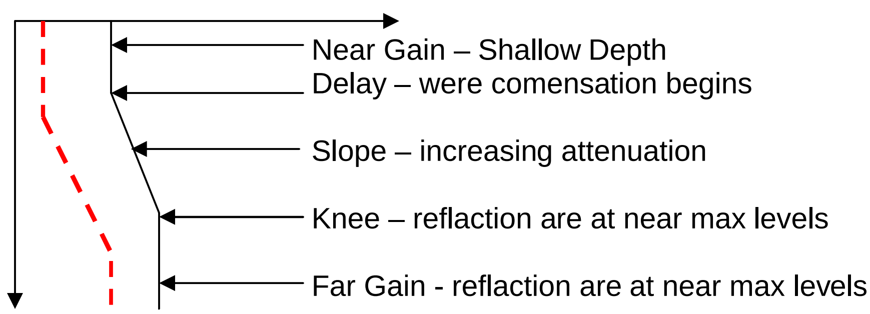
- Sends voltage that excites the PZT's
- Can alter / improve the signal to noise ratio
- Determins Pulse Repitition Period
- Thermal Index -
- Mechanical Index -
- Signal to Noise Ratio –
    - o High Ratio - Signal stronger than the noise
    - o Low Ratio – Signal is closer as the noise more contamination.
- Modifies brightness of entire image
- Disirable – low pulser voltage for Bioeffect resons

14-3 Beam Former

- Apodization – when focusing stronger electrical signals are sent to the inside PZT's and get weaker gradually to the outside PZT's this eliminates Gated and Side lobes which cause noise.

14-4 Receiver – Receiver operation: 10 uvolt's normal received value

- Amplification – equally amplifies all signals normals 60-100 dB
- Compensation – TGC's (Time Gain – Depth Gain or sweep Gain)
  Depends on Attenuation - higher the frequency - higher the attenuation
  (slide the TGC's to the right as needed & Deeper ifs attenuation is less)
  Less MHz transducer – less attenuation – longest delay - deeper TGC's



- Compression – Gray scale mapping
- Demodulation – rectification & Smoothing
- Reject – (threshold or suppression) allows low-level gray scale information to be shown or not shown.

14-5 Display - see chapter 15
14-6 Storage - see chapter 15

14-7 Master synchronizer

Operation	Adjustable	Signal Processed	Effects on Image
Amplification	Yes	All threads receive equal amplification	Entire image gets brighter
Compensation	Yes – TGC's	Depends on depth will increase signal	Image will be uniformly bright from top to bottom

Compression	Yes	Signal treated differently depending on strength – enhances weak, compresses tall waves	Changes gray scale mapping
Demodulation	NO	Prepares Electrical signal to be suitable for CRT display	NONE
Reject	YES	Only weak signals affected – strong signals remain unchanged	Weak echoes are present or eliminated for image

14-8 Output Power vs. Receiver Gain

Output Power – Image brightens by adjusting the strength of the sound pulse sent to the body
- Improves signal to noise ratio – (Low)

Receiver Gain – (Amplification) – Alters strength of voltage in the receiver
- High create brighter image

15-1 Display & Image Storage

- CRT Cathode Ray Tube
  - o Displays in 1/30th of a second = 525 horizontal lines of display
  - o Interlace 1/60th of a sec odd lines + 1/60th of a sec even scan lines = 525 Horizontal lines

15-2 Bistable – bi – 2
- Bistable image is black and white

15-3 Display controls - Contrast – Brightness

- Scan Converter – stores information and translates the information from the spoke format to video format.

15-4 Analog vs. Digital

Analog Numbers	Digital numbers
Real World	Computer World
Unlimited # of Choices	Limited Choices
Continuous Values	Discrete Values

Analog Scan Converter	Digital Scan converter
Image Fades	Uniformity
Image Flickers	Stability
Instability	Durability
Deterioration	Speed
	Accuracy

15-5 Pixels – Picture Elements The pixel is the smallest block of a digital picture
- Pixel Density – the number of picture elements per inch

High Pixel Density	Low Pixel Density
Many Pixels Per inch	Few Pixels Per inch
Smaller Pixels	Larger Pixels
More Detailed Image	Less Detailed Image
Higher Spatial Resolution	Lower Spatial Resolution

15-6 BIT – Binary Digit - Smallest amount of computer memory

- Bistable – having the value of either 0 or 1

- BYTE - a group of 8 bits of computer memory 10011111 8 BITS = 1 BYTE

More Bits Per Pixel	Fewer Bits Per Pixel
More Shades of Gray	Less Shades of Gray
Improves contrast resolution	Degrades contrast resolution

- Calculating the number of gray shades – 2 squared by the number of memory bits
- $2^{\text{number of bits}}$ = How many shades of gray is in 5 bit of memory 2^5= 2*2*2*2*2=32 different shades of gray

Summary

Pixels	Bits
Image Element	Computer Memory
Image Detail	Gray Shades
Spatial Resolution	Contract Resolution

15-7 Pre & Post Processing

- Pre Processing – Manipulation of data BEFORE storage in the scan converter
- Post Processing - Manipulation of data AFTER storage in the scan converter

Pre Processing	Post Processing	Either Pre or Post
TGC's	Any changes after freeze frame	Persistence
Log Compression	Black/white inversion	Frame Averaging
Write Magnification - ZOOM	Read magnification- DEPTH	Edge Enhancement
	Contract Variation	Smoothing
		Fill-in-interpolation

15-8 Read Write Magnification

Write Magnification - ZOOM	Read Magnification- DEPTH
Acquires New Data	Uses old data
Pre Processing	Post Processing
Identical Pixel Size	Larger stretched Pixel Size – BLURS Pic
Improved Spatial Resolution	Unchanged Spatial Resolution
Possible improved temporal resolution	Unchanged temporal resolution

16-1 Dynamic Range - Method of reporting the extent to which a signal can vary and be accurately measured = **units of dB**

Component	Dynamic range
Transducer	120 dB
Receiver	100 –120 - dB
Scan Converter	40 – 50 dB
Display	20 – 30 dB
Archive	10 – 30 dB

Calculating Dynamic range – Count the zeros and multiplied by 20
10 – 20 dB
100 – 40 dB
1,000 – 60 dB
10,000 – 80 dB
100,000 – 100 dB

<u>17-1 Harmonics and Contrast agents</u>

- Fundamental frequency – Initial sound wave's frequency transmitted into the body
- Harmonic Frequency – Twice the fundamental – also called 2nd harmonics
- Fundamental Image – Image created by processing the Initial frequency transmitted into the body
- Harmonic Image – Image created reflections that are twice the Twice the fundamental frequency

Linear behavior – Proportional or even manner
Non-linear behavior – irregular or disproportional manner

<u>17-2 Contrast Agent</u> – Microbubbles – gas bubbles entrapped in a shell made of perflutren lipid microspheres Microbubbles are less than 10 µm in diameter.

Strong Reflectors

- Contrast harmonics small amount of energy converted from fundamental F to harmonic F causes non-linear behavior. Created during the reflection of the sound. Measured as Mechanical Index
- Non-linear behavior – uneven behavior of bubble size
- Mechanical Index – The amount of contrast harmonics produced – depends on the frequency of the transmitted sound
- Lower MI – less pressure – high Frequency
- Higher MI- more pressure – low Frequency

<u>18-1 Hemodynamics</u> – the study of blood moving through the body.

- Flow – Volume floe Rate – the volume of blood moving during a particular time.
  - Units = liters /min, ml/s
- Velocity speed of the blood moving from one place to another.
  - Units cm/s, m/min

<u>18-2 Three Forms of Flow</u>

- Pulsatile Flow – Blood moving at variable speeds – From Cardiac Contractions - **Arterial**
- Phasic Flow – Blood moves at various velocities – Respiration changes - **Venous**
- Steady Flow – Steady Flow – Consistent speed or velocity – Venous flow when patient stops breathing

<u>18-3 Laminar vs. Turbulent</u>

- Laminar Flow – Flow Stream lines are parallel and aligned.
  - Plug Flow – Blood moving at same velocity – flat shaped
  - Parabolic flow – inner layers move faster than wall layers – bullet shaped
- Turbulent Flow – chaotic flow patterns in many different directions and many speeds, Eddies.
  - Flow Sounds – Murmurs, Palpable Murmurs and Bruit
  - Vibrations – Thrills
- **Reynolds number – predicts turbulent flow 2000 – 2500**

- **Reynolds number = Average flow speed * diameter of tube *density / viscosity (unit less)**

18-4 Moving measurements

- Energy Gradient – **Flow from one location to another = Pressure difference / distance between pressures**

18-5 Forms of Energy

- Kinetic Energy – moving objects heavy objects move swiftly – high Kinetic energy
- Pressure Energy – Stored potential energy, energy for circulating blood by overcoming resistance – when valve opens energy propels
- Gravitational energy – energy associated with elevated objects – Down hill skiers have gravitational energy
- Energy losses in the circulation
  - Viscous Energy Loss - high velocity fluids take more energy to move causing energy loss, honey is viscous alcohol is not.
  - Frictional Energy Loss - energy is converted to heat as one object rubs against another. – Blood sliding across vessel walls
  - Inertial Energy Loss – **Sir Isaac Newton, an object in motion will stay in motion, an object at rest will stay at rest –** fluids will resist change in its velocity

18-6 Stenosis – is a narrowing in the lumen of a vessel

Effects on Stenosis
Change in flow direction
Increased velocity as vessel narrows
Turbulence downstream from the Stenosis
Pressure gradient across the Stenosis
Loss of pulsatility

Ohm's Law – The movement of fluid through a tube and the movement of electricity through a wire are similar
Pressure gradient = flow * resistance **= voltage = current * resistance**

Poiseuille's law - Law stating that the fluid resistance in a long, straight tube with steady, irrotational (non rotating flow) flow is proportional to its length and viscosity and inversely proportional to the fourth power of its radius.

Bernoulli's Law- total fluid energy along a streamline of fluid of flow is constant.

18-7 Venous Hemodynamics

Pressure	Shape	Volume
Low	Dumbbell	Low
Slightly higher	Round	Full
Much higher	Round	Overfilled

18-8 Hydrostatic Pressure – (mmHg) - pressure related to the weight of blood pressing on a vessel measured at a height above or below heart level

Measured Pressure = Circulatory Pressure + Hydrostatic Pressure

Hydrostatic Pressure Supine patient = 0 Ankles, knees, heart & top of head.

Hydrostatic Pressure Standing Patients

Site	Level	Hydrostatic Pressure
Top of head	Above heart	-30 mmHg
Mid chest	Heart level	0 mmHg
Waist	Slightly below heart	50 mmHg
Knee	Somewhat below heart	75 mmHg
Ankle	Far below heart	100 mmHg

With circulation pressure of 130 mmHg:
The pressure in the toe is: 130 + 100 = 230 mmHg
The pressure in the upper arm: 130 + 0 = 130 mmHg
The Pressure in the finger when the arm is pointed to the sky 130 – 50 = 80 mmHg

18-9 Breathing and venous flow

Inspiration	Expiration
Diaphragm moves downward toward abdomen	Diaphragm moves upward into thorax
Abdominal pressure increases	Abdomen pressure decreases
Flow in the legs decreases	Flow in the legs increases
IVC flow decreases	**IVC flow increases**
Thoracic pressure decreases	Thoracic pressure increases
Flow in the arms increase	Flow in the arms decrease
SVC flow increases	**SVC flow decreases**

19-1 Doppler
- Doppler sift – *change in frequency* do to movement (per second)
- **Doppler Shift – IS Directly related to frequency of transducer**
    - High Transducer Frequencies will produce ALIASING
- **Doppler Shift – IS Directly related Velocity of red blood cells**
- **Doppler Shift Frequency** - is low Frequency riding on higher frequency
    - Typical range – 20 Hz – 20 kHz
    - The return is low Frequency
    - The process of extracting the low frequency is call demodulation

Reporting Doppler Findings –
- Doppler Shift – (Hz) Will be in small range – 20 Hz – 20kHz +/-
    - WILL change is transducer is changes, directly related to Transducer frequency
- Velocity – (m/s) – **Velocity of red blood cells**
    - WILL not change when Transducer frequency changes
    - WILL change when the angle changes
- Imaging Processing:
    - Phase Quadrature - Function of proccessing time - 90^o delay
    - Heterodyne Frequency shifting – assists in filtering frequencies

PEDOFF Probe – Pedoff probe – Dedicated continuous wave Doppler probe.
- Two Crystals – one send one receives – shape semi circle
- No backing material
- Narrow bandwidth
- High Q-factor
- High sensitivity
- Frequency of Pedoff is dictated by the electrical signal sent from the US system not the crystal.

- Demodulation – extracting low doppler F from high transducer frequencies
    - o Two set process that changes electrical signals in the receiver to form suitable for CRT
- Positive Doppler shift – red blood cells moving toward transducer
- Negative Doppler shift - red blood cells moving away transducer

<u>19-2 Speed vs. Velocity</u>

- Speed = Magnitude (length) Distance red blood cells move in 1 second
    - o Speed is simple 50 miles per hour
- Velocity = Magnitude and Direction =
    - o Velocity would be 50 miles per hour going south on the road
- Cosine of the angle - % of true velocity measured is dependant on the Cosine of the angle

Angle Degrees	Cosine
0^o	1.0
30^o	.87
60^o	.5
90^o	0

120^o	-.05
150^o	-.87
180^o	-1.0

Continuous wave Doppler –

Advantages	Disadvantages
Two Crystals one to send one to listen	Unable to measure exact location of doppler signal
Measures higher velocities	**Range Ambiguity** – signal that arise from all the red blood cells in the region of overlap between the sending and listening beams
Good Temporial Resolution	Lack of TGC's

- Duplex imaging – Simultaneous anatomic imaging and doppler
- Doppler Analysis – Complexe signals broken down into its more basic ingredients FFT
- Doppler Spectrum – Gray scale is determined by the number of reflectors (red blood cells)
- Reflectors determine amplitude of signal
- Amplitude of echo- dependent on number of reflectors

Pulse Wave Doppler – One crystal both sends and receives at sample gate

Advantages	Disadvantages
Selects exact location	Inaccurate on High velocities
Good Temporial Resolution	Aliasing - could be shown as negative velocities (false blood moving away)

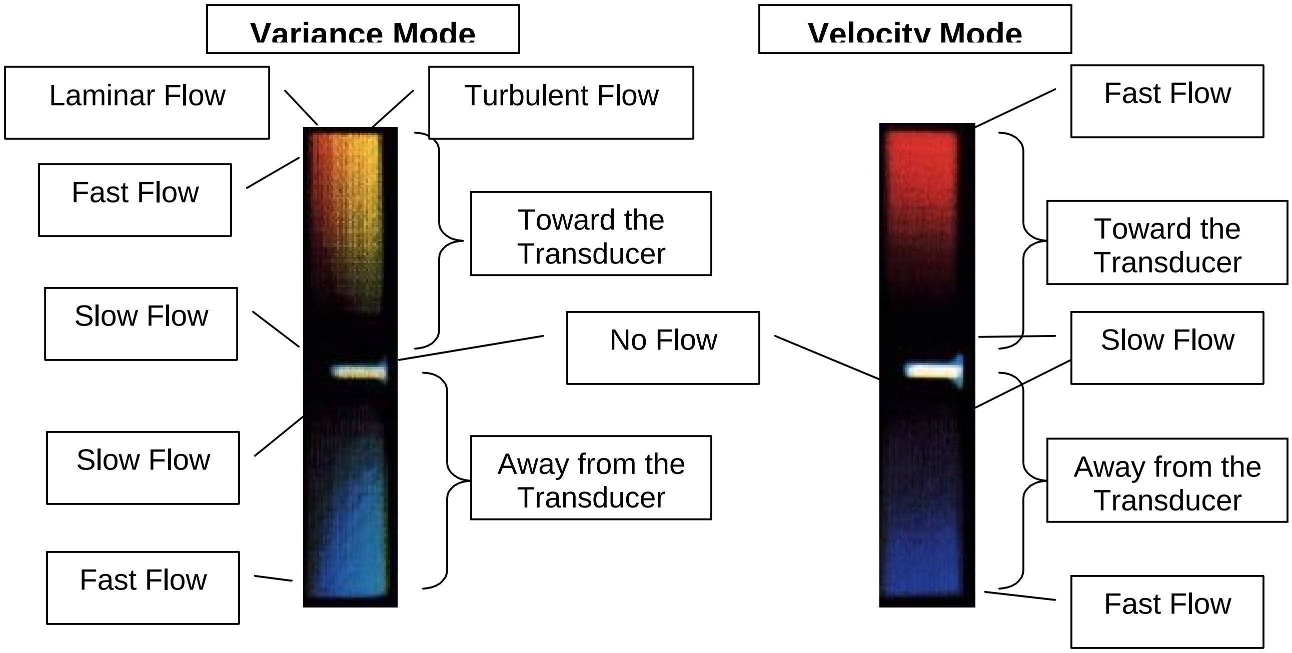
- **<u>Nyquist limit</u>**

- Highest Doppler frequency that can be measured with out the appearance of aliasing.

Nyquist limit (Hz) = Doppler Shift Frequency > half the PRF (PRF/2)

Less aliasing	More aliasing
Slower Blood Velocity	Faster Blood Velocity
Lower frequency transducer	Higher frequency transducer
Shallower gate (High PRF)	Deep gate (Low PRF)
Continuous wave Doppler	Pulse Wave Doppler

19-3 Color Flow Doppler – suffers from poor temporal resolution – 2 Modes useds

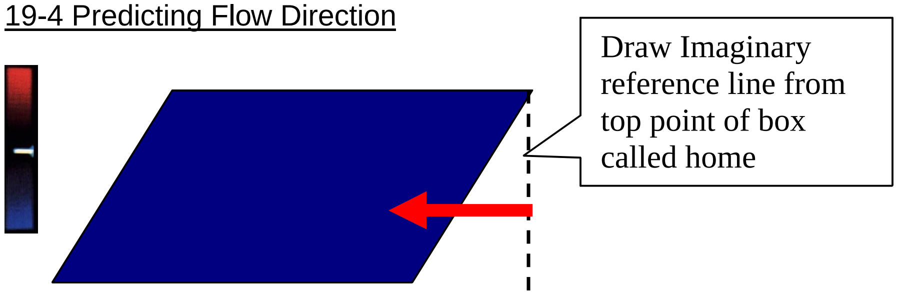


Variance Mode – Identifies Turbulant flow –

- Multiple colors will not appear on screen if no Turbulence is detected

Velocity Mode - Identifies Flow direction

19-4 Predicting Flow Direction



Your home line is the transducer and since the vassal is blue and the scale shows blue is moving away from the transducer than the flow in this picture is moving right-left

Color Doppler - measures Mean velocity
Spectral Doppler – CW & PW – measures peak velocity

Power Doppler – (energy mode, color angio)

- Only identifies presents of blood
- Non-directional

Advantages	Disadvantages
Increased sensitivity to low flow	Can not measure velocity or direction
Unaffected by angle unless exactly 90°	Low frame rate reduces resolution
No aliasing	Susceptible to movement –color burst

19-5 Spectral Analysis

Two methods of Spectral Analysis

Fast Front Transformer (FFT)	Autocorrelation
Exceedingly accurate	Only Color Doppler
Displays all velocities	Faster than FFT
Digital Doppler (PW & CW)	Digital
More accurate than Autocorrelation	

Spectral Doppler also shows Laminar and turbulent flows

- If spectral form is hollow – Laminar
- If spectral form is filled in – Turbulent
    - The number of reflectors also plays a part in gray scale (this also determines the amplitude of the signal)

20-1 Artifact - error in imaging

- Causes - Violation of assumptions - Equipment malfunction - Physics of ultrasound - Operators error

Artifact occur in Violation of 6 assumptions

1. Sound travels in a straight line
2. Sound travels directly to a reflector and back
3. Sound travels in soft tissue at exactly 1,540 m/s
4. Reflections arise only from structures positioned in the beam's main axis
5. The image plane is very thin
6. The strength of a reflection is related to the characteristics of the tissue creating the reflection

Imaging Characteristics

- Hyperechoic – Brighter than surrounding tissues or tissues that appear brighter than normal
- Hypoechoic – Portion of am image that are not as bright as surrounding tissues
- Anechoic – An extreme form of Hypoechoic, mainly with out echoes
- Isoechoic – Describes structures with equal echo brightness
- Homogeneous – A portion of tissue or an image that has similar echo characteristics throughout
- Heterogeneous – A portion of tissue or an image that has differing echo characteristics throughout
- Echogenic – Tissue that produces an echo
- Sonolucent – No Echos or echo free

Propagation Group

Reverberation – Appears in multiples – appears as equal spaced – located parallel to the beams main axis – located at ever-increasing depths **Caused by beam bouncing between two reflectors** (resembles rungs of a ladder)

Comet tail – appears as a single long Hyperechoic echo – located parallel to the sound beams main axis.

Edge Shadow – (Ring Down) - Is an ultrasound artifact that appears as a solid streak or a series of parallel bands **radiating away from gas collections**, this Hypoechoic region at edges of an object – result form beam spread after striking a curved reflector – extends downward from the reflectors edge, parallel to the beam – prevents visualization of true anatomy on the scan

Mirror Image – A Second copy of a true reflector – the copy appears deeper than the true reflector – A bright reflector the mirror, lies on a straight line between the artifact and the transducer – True reflector and artifact are equal distance from the mirror. **Beam bounces off strong reflector which acts like mirror**

LOBES – Side and grating Lobes **occurs when sound energy strikes object other than in the beam's main axis** - Second copy of true reflector –the artifact and the true reflector are located side-by-side at the same depth.

Refraction – When Sound pulse changes transmission - reflector are located side-by-side at the same depth
OTHERS
Section thickness
Axial Resolution
Speckle
Grating Lobes
Speed error
Range Ambiguity

Attenuation Group

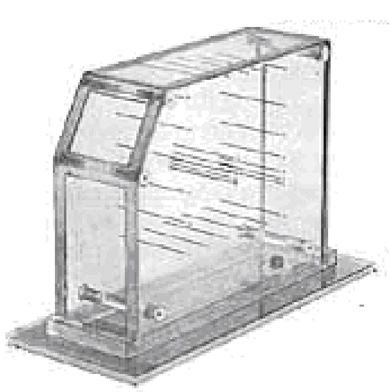
Shadow – hypo or anechoic – **result of too much attenuation** – located beneath the structure with abnormally high attenuation – prevents visualization of true anatomy on the scan.

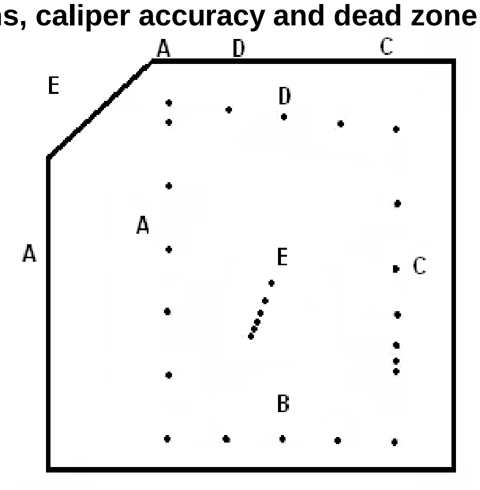
Enhancement – Solid Hyperechoic region beneath tissues with abnormally low attenuation – **result of to little attenuation** – located beneath the structure with abnormally low attenuation

Focal Enhancement – A Hyperechoic side-to-side region- **the result of increased intensity at the focus**

21-1 Quality Assurance – Routine periodic evaluation of an ultrasound system to optimize image quality

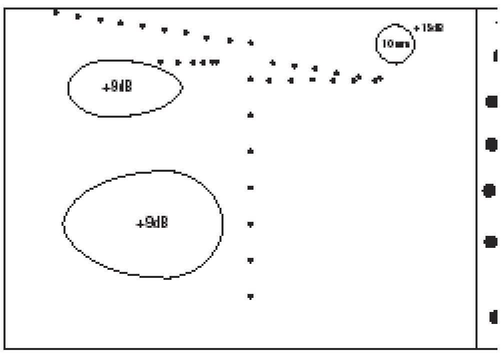
21-2 AIUM 100 mm Test Object – Fluid filled with the speed of sound characteristics of 1.54 km/s for testing – **Axial & lateral resolutions, caliper accuracy and dead zone**



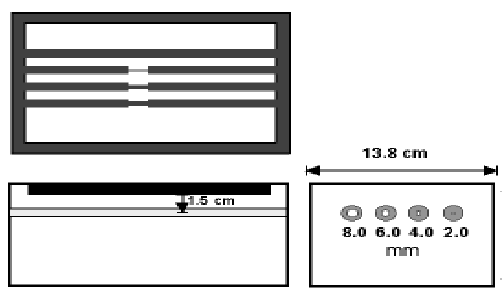


Group	Scan Face	Provides
Pin Group C	Top Face	Lateral Resolution
Pin Group A	Side Face	Lateral Resolution
Pin Group E	Diagonal Face	Lateral Resolution
Pin Group A	Top Face	Axial Resolution
Pin Group D	Top Face	Dead Zone

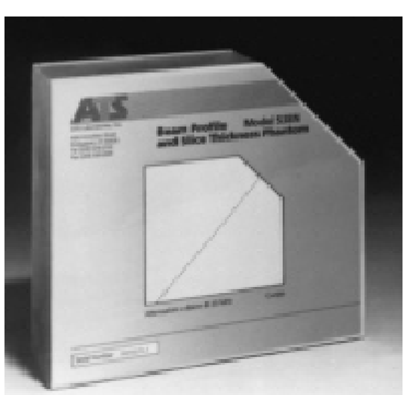
<u>21-3 Tissue Equivalent Phantom</u> – Ultrasonic features similar to soft tissue so test for **Gray scale tissue texture, multi focus and adjustable focus** phased array transducers.

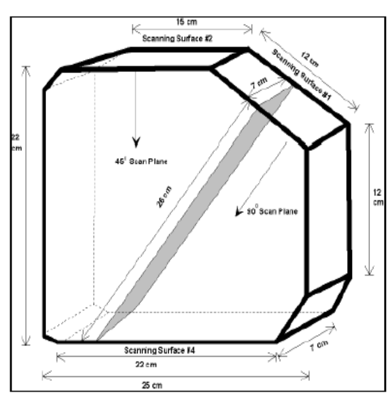


<u>21-4 Doppler Phantoms</u> – using vibrating strings, moving belts & fluid flow – test all doppler modes such **as PW, CW, power doppler and color Doppler**



<u>21-5 Slice Thickness Phantom</u> – (Elevational resolution) Evaluates Slice thickness –**Lateral Resolution, Pulse length & axial resolution.**





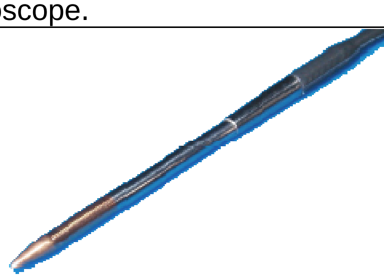
22-1 Bioeffects – Since the majority of sound energy stays in the body, it is important to know the output of the transducers and the effects of the sound energy on the human body.

- Biologic effects – effects of sound on tissue

22-2- tools used to check transducers

Hydrophone – Microprobe – A voltage related to the pressure of the wave is created and displayed on the oscilloscope. **Determines sound beam shape, period, PRP, PRF and pulse duration – provides relationships between the pressure signal, voltage created, intensities and other output** measurements.

Two types of Hydrophones:

Needle	Membrane - Drum
A small needle like probe or transducer with tiny PZT crystals attached to end attached to an oscilloscope.	The center is constructed of very thin membrane made from PZT plastic
	

Principles:

- Dosimetry – the science of identifying & measuring the characteristics of an ultrasound beam

22-3 Types of Bioeffects studies

In Vivo – research preformed **within** the living body – lung tissue studies
In Vitro - research preformed **outside** in the living body – computer model estimates
AIUM statement -In Vitro is viewed with caution

Mechanistic approach	Empirical approach
Broad exposure range can be evaluated (+)	No need to understand mechanism (+ / -)
Uncertainty about assumptions (-)	Biological significance is obvious (+)
Are other mechanisms involved (-)	Species difference may alter results (-)

- Cavitation – the production and behavior of bubbles in a liquid medium.
    - Stable – oscillate in diameter with passing pressure variations
    - Transient (Collapse) – occurs when bubbles become large and explode.

Stable	Transient
	Also called normal or inertial
Oscillating bubbles	Bursting bubbles
Micro-streaming and shear stresses	Shock wave & very high temperatures
Low MI	High MI (mechanical index)

- Risks & Benefits relationship – Mandated clinical ultrasound is that the benefits to the patient must outweigh the risk of the exam.

<u>22-4 AIUM Statements</u>

AIUM statement on clinical Safety – Diagnostic Ultrasound has been used since the 1950's, There has been no confirmed biological effects on patients or instrument operators caused by exposure.

AIUM statement on Prudent Use – sonography involves application of the ALARA principle. By requiring medical indication and by using minimum output and exposure time in diagnostic examinations, exposure and risks are minimized.

The AIUM has stated: That there have been no independently confirmed, significant Bioeffects reported to occur in mammalian tissue exposed to focused SPTA intensities if less than 1 W/cm

Intensities to note: SPTA