Ultrasound – Lecture 2
Bushberg – Chapter 16
RSNA & AAPM Physics Curriculum: Module 15

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a copy of this lecture may be found at:
http://courses.washington.edu/radxphys/PhysicsCourse.html

 1

Sources of information on Fluoroscopy

- Bushberg Chatper 16
- AAPM/RSNA web modules
  - Basic US Imaging and Display
  - Image Quality – Artifacts – Doppler
  - US – Concepts and Transducers
- AAPM/RSNA Physics Tutorials
  - Topics in US: Doppler US Techniques: Concepts of Blood Flow Detection and Flow Dynamics
    Radiographics 2003; 23: 1315-1327
  - Topics in US: B-mode US: Basic Concepts and New Technology
    Radiographics 2003; 23: 1019-1033
- AAPM/RSNA Physics Curriculum – Module 15 Outline

 2

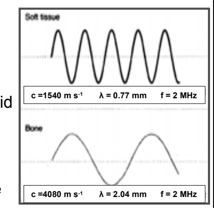
Lecture Objectives

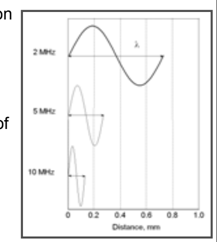
- Lecture 1
  - Characteristics of sound waves
    - Sound propagation; wavelength, frequency, amplitude, etc; pressure, intensity, dB scale
  - Interactions of ultrasound with material
    - Impedance, reflection, refraction, scattering, attenuation
  - Introduction to image acquisition
    - U/S components, pulse-echo imaging operation
- Lecture 2
  - Transducers
  - Image properties and qualities
    - Near vs. far field; Fresnel zone;
    - Spatial resolution (axial, lateral, and elevational), distance measurements, contrast
  - More on image acquisition
    - image formation (transmit power, gain, TGC, frame rate, etc)
- Lecture 3 – June 24th
  - Clinical ultrasound lecture – Dr. Tasneem Lalani
    - Doppler, harmonic imaging, 3D, etc; discussion on artifacts and diagnosis

 3

Lecture 1 Review – Major Topics

- Ultrasound is mechanical energy imparted in tissue
  - Considered pulse-echo imaging ("call and response")
  - Medical U/S – 2 to 10 MHz
- U/S imaging – 2D imaging; anatomic distance, volume, and fluid velocity measurements; motion studies; 3D/4D imaging
- Characteristics of Sound
  - Frequency – unaffected by Δc; independent of tissue
  - At a tissue interface – acoustic impedance (Z) gives rise to change in sound speed and therefore wavelength
- For thick body parts – lower frequency → increased penetration
  - Ex: abdomen imaging (3.5-5 MHz transducer)
- For superficial body parts – higher frequency → improved resolution
  - Ex: thyroid or breast imaging (7.5-10 MHz transducer)
- Imaging through bone & air generally not possible b/c of lack of transmission (interface reflection due to large ΔZ)





$$c = \lambda \cdot f$$

$$c = \sqrt{\frac{B}{\rho}}$$

$$I \propto P^2$$

$$\text{Relative Intensity (dB)} = 10 \log\left(\frac{I_2}{I_1}\right)$$

c.f. Dowsett, et al. The Physics of Diagnostic Imaging, 2nd ed., p. 514.

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 473.

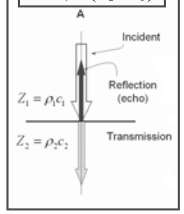
 4

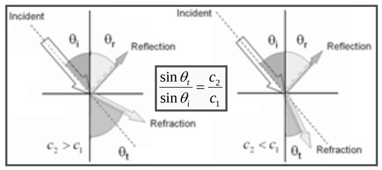
AAPM / RSNA Physics Curriculum
Module 15: Ultrasound
Lecture 2 of 2

Lecture 1 Review – Major Topics

- Acoustic Impedance (Z) – gives rise to tissue interactions with U/S waves
- Interactions of U/S with tissue
  - Reflection – occurs w/perpendicular and non-normal angles of incidence (θ_i)
    - Transmission $T_I = 1 - R_I$
  - Refraction – partial reflection (where $\theta_i = \theta_R$), partial transmission w/ Δ transmission angle (θ_T)
    - If $c_1 < c_2$, then $\theta_T > \theta_i$
    - If $c_1 > c_2$, then $\theta_T < \theta_i$
  - Scatter
    - At a boundary or small objects; specular v diffuse reflectors
    - Depends on # scatters, Z difference, size of scatters, and frequency
    - Hyperechoic vs hypoechoic anatomy
  - Absorption
    - Acoustic energy converted into heat
  - Attenuation
    - Half-value thickness (3 dB Δ intensity)
    - Rule of thumb: 0.5 dB per cm per MHz
    - Increasing frequency → decrease HVT

$$R_I = \frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$





$$\frac{\sin\theta_t}{\sin\theta_i} = \frac{c_2}{c_1}$$

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 478.

 5

Ultrasound Image Acquisition

 6

Ultrasound Image Data Acquisition

Modes of Operation

- A-mode: amplitude
  - Single pulse echo
  - Clinical Application – ophthalmology
- B-mode: brightness
  - Brightness is proportional to the signal amplitude
  - Used in M-mode and 2D grey-scale imaging
  - Generates a 2D image; covers a plane of interest rather than on single line of transmit/receive
- M-mode: motion
  - Fixed transducer position and beam direction – measure of motion patterns for anatomy along a single line
  - Recent developments in Doppler U/S replaced the need for M-mode

 7

Ultrasound Image Data Acquisition

Pulse Echo Operation

- Time delay b/w transmit and receive is directly related to the depth of the interface
- U/S assumes the speed of sound in soft tissue (1540 m/sec or 0.154 cm/μsec)

$$Time[\mu\sec] = \frac{2D[cm]}{c[cm/\mu\sec]} = \frac{2D[cm]}{0.154\,cm/\mu\sec} = 13\mu\sec\cdot D[cm]$$

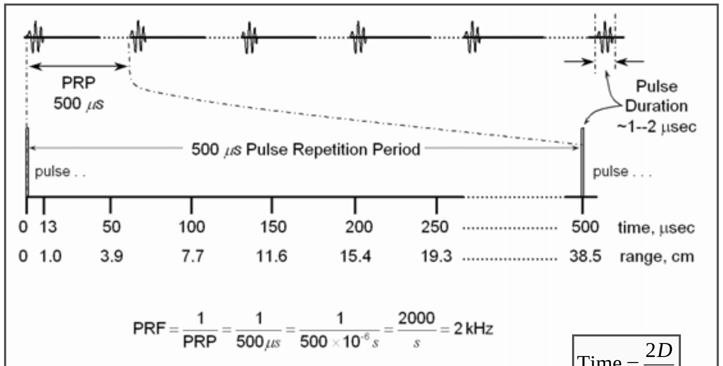
$$\text{Distance}\,[cm] = 0.077 \cdot Time(\mu\sec)$$

- Transmit the signal
  - Pulse repetition frequency (PRF) – # of times the transducer is pulsed per second (typically, 2 to 4 kHz)
- Listen for echoes
  - Pulse repetition period (PRP) – time between pulses; the inverse of the PRF

 8

Ultrasound Image Data Acquisition

Pulse Echo Operation



$$\text{Time} = \frac{2D}{c}$$

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 503.

Ultrasound Image Data Acquisition

Pulse Echo Operation

- Increasing the frequency of the pulses (PRF) results in less listening time
  - If a new pulse is emitted before the most distance echo from the previous pulse returns to the transducer, the echo will be "mapped" as a prompt echo (indicating a signal for a return echo close to the transducer)
- Maximum range – determined by how long the receiver "listens" for echoes

$$\text{Max Range}\,[cm] = \frac{c[cm/\sec]\cdot PRP[\sec]}{2}$$
$$\text{Max Range}\,[cm] = \frac{154{,}000 cm/\sec\cdot PRP[\sec]}{2}$$
$$\text{Max Range}\,[cm] = 77{,}000 cm/\sec\cdot PRP[\sec] = \frac{77{,}000 cm/\sec}{PRF[Hz]}$$

$$\text{Max Range}\,[cm] = \frac{c\cdot PRP}{2}$$

Ultrasound Image Data Acquisition

Pulse Echo Operation

Review Question: For a beam with a 2kHz pulse repetition frequency, what is the corresponding PRP and max range?

$$PRP[\sec] = \frac{1}{PRF[Hz]} = \frac{1}{2kHz} = 0.0005\sec = 500\mu\sec$$

$$\text{Max Range}\,[cm] = \frac{154{,}000 cm/\sec\cdot 0.0005\sec}{2} = 38.5cm$$

$$\text{Or we know this equation: Time} = \frac{2D}{c} \text{ and Time} = \frac{1}{\text{f}}$$

$$\text{Max Range}\,[cm] = \frac{154{,}000 cm/\sec}{2\cdot(2kHz)} = 38.5cm$$

Ultrasound Image Data Acquisition

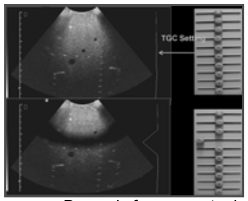
Pulse Echo Operation

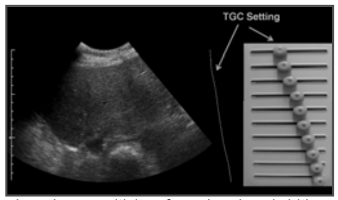
- *Caution!!!* Do not confused PRF with the frequency of the transducer!!
  - Transducer frequency is MHz – pulse repetition frequency (PRF) is kHz
  - Transducer period is μsec – pulse repetition period (PRP) is msec
- Previously, we talked about high frequency transducers, which have better resolution, but poor depth penetration. Because the limited depth of penetration, more pulses can be emitted (higher PRF) because the echoes do not have as far to travel.
- Conversely, low frequency transducers (used for penetration), need longer PRP (to listen for distance echoes), therefore low PRF.

Ultrasound Image Data Acquisition

Pulse Echo Operation

- Receiver Mode & Signal processing
  - Echo has an associated time delay (depth of echo) and amplitude (contrast)
  - Gain adjustments
    - Time gain compensation (TGC) – ***user-adjustable*** amplification of signal to compensate for beam attenuation
    - Ideal TGC – equally reflective boundaries equal in signal amplitude, regardless of depth





  - Dynamic frequency tuning – changing sensitivity of receiver bandwidth; echoes from shallow depths are tune to high frequency, echoes from deeper structures are tuned to lower frequencies

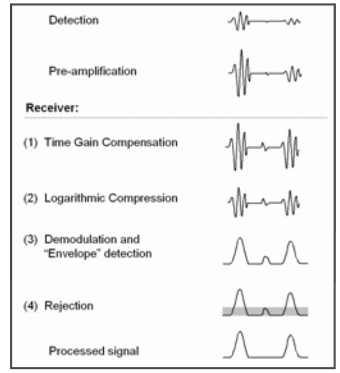
c.f. Zheng F. Lu et. al. AAPM/RSNA Web Modules. Basic Ultrasound Imaging and Display. Section IV.C.

13

Ultrasound Image Data Acquisition

Pulse Echo Operation

- Receiver Mode & Signal processing



  - Dynamic range compression – recall: transmitted signal is 10,000x higher amplitude than the reflected tissue echoes (~40 dB decrease in signal intensity)
    - Using logarithmic amplification, increase the small echo amplitudes and decrease the large echo amplitudes
    - Produces an output signal proportional to the log of the input signal – achieves appropriate range of signals for gray scale display
  - Rectification – inverts negative amplitude signals
  - Rejection level adjustment – sets a threshold signal amplitude; removes significant low-amplitude signal (noise) and clutter generated from scattered sound or electronics (***user-adjustable***)

14

Ultrasound Image Data Acquisition

Pulse Echo Operation

- Electronic scanning & real-time display
  - # A-lines is approximately equal to the # transducer elements
  - Scan converter – creates 2D images from echoes received; a single frame is created from a number of A-lines (N) acquired across a FOV
    - Increased N → better image quality, longer frame rate

$$\text{Frame Rate} = \frac{1}{\text{Time per frame}[\text{sec}]}$$

  - Frame rates – typically 15-40 frames per second
    - Motion can be followed
  - Maximum frame rate – limited by N and penetration depth (D)

$$\text{Frame Rate} = \frac{1}{\text{T}_{\text{frame}}} = \frac{1}{N \cdot T_{A-line}} = \frac{1}{N \cdot 13\mu\text{sec} \cdot D[cm]}$$

Recall:

$$Time[\mu\text{sec}] = \frac{2D}{c_{soft\,tissue}} = 13\mu\text{sec} \cdot D[cm]$$

$$\text{Distance}[cm] = 0.077 \cdot Time(\mu\text{sec})$$

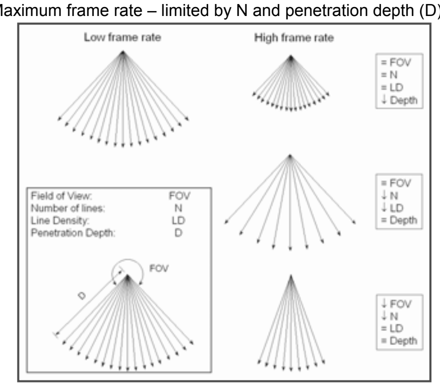
15

Ultrasound Image Data Acquisition

Pulse Echo Operation

- Electronic scanning & real-time display
  - Maximum frame rate – limited by N and penetration depth (D)

<u>*Typcial clinical frame rates*</u>: 15-40 frames per second



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 514.

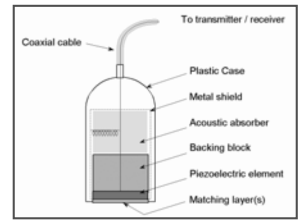
16

Ultrasound Transducers

17

Ultrasound Transducers

A transducer is…
- Produces *and* detects the U/S waves
- Ceramic elements with electro-mechanical properties
  - Transmit – converts electrical energy (applied voltage) to mechanical energy
  - Receive – converts mechanical energy to electrical energy
- Major parts of a transducer
  - Piezoelectric (PZT) elements – functional component of the transducer
  - Matching layer – reduces acoustic impedance b/w PZT & tissue
  - Backing (damping) block – absorbs backwards directed (stray) U/S from housing



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 484.

18

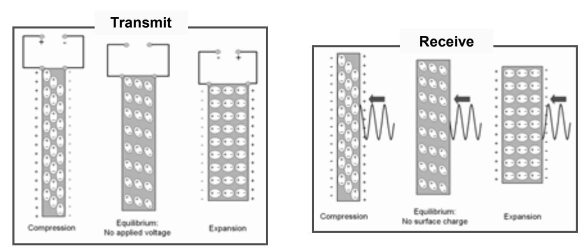
Ultrasound Transducers

Parts of a Transducer
- Piezoelectric (PZT) elements – functional component of the transducer
- The piezoelectric effect
  - Transmit mode – electrical energy is converted to mechanical (sound) energy by physical deformation of the crystal structure
    - Applying an alternating current to the crystal of a transducer causes it to expand and contract (vibrate), producing sound at that vibrational frequency
  - Receive mode – conversely, mechanical pressure applied to the surface of the crystal during receive mode is converted into electrical energy
    - On reception of a sound echo, the crystal vibrates at the sound frequency of the echo and produces an electrical current
  - U/S transducers – synthetic piezoelectric ceramic, often lead-zirconate-titanate (PZT)

19

Ultrasound Transducers

Parts of a Transducer
- Piezoelectric (PZT) elements – functional component of the transducer
  - Electrical dipole – molecular arrangement that contains positive and negative charge with no net charge
    - External pressure changes alignment of molecules from equilibrium that causes an imbalance of charge distribution
    - A potential difference (voltage) is created across the element (one surface has net positive charge, the other has net negative charge)



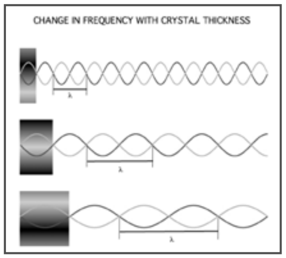
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 485.

20

Ultrasound Transducers

Parts of a Transducer

- Single element resonance transducer
  - An undamped transducer crystal vibrates like a tuning fork
    - Resonance transducers – *wavelength is twice the thickness of the crystal*, where the frequency is called the resonant, or center, frequency
    - At the resonant frequency, the transducer produces the maximum intensity pressure wave. A transducer also produces and is sensitive to harmonics, or multiples of its resonant frequency.



Review Question

- To achieve a 5-MHz center frequency using a 5-MHz transducer, what thickness should the crystal be?
- *Note*: the speed of sound in PZT is ~4,000 m s^{-1}

$$\lambda = \frac{c}{f} \qquad \lambda = \frac{c}{f} = \frac{4{,}000\,m/s}{5MHz} = 0.8mm$$

- The xstal thickness should be ½ λ.
- Therefore, 0.4mm thick PZT

c.f. Scherzinger & Stamm. AAPM/RSNA Web Modules. Ultrasound Concepts and Transducers. Section VI.A.

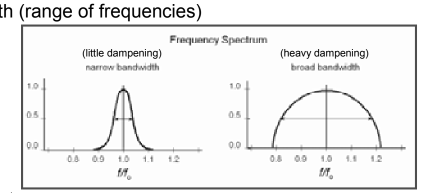
21

Ultrasound Transducers

Parts of a Transducer

- Backing (damping) block – layered on back of PZT
  - Absorbs backward directed or stray U/S waves in housing
  - Dampens the PZT vibration to produce a pulse with short spatial pulse length (i.e. limits the vibration of the PZT element(s) to a small # cycles)
- Spatial pulse length = # cycles times wavelength
- Dampening of the vibration is known as "ring-down" and determines U/S bandwidth (range of frequencies)

"Purity of center frequency"



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 487.

22

Ultrasound Transducers

$$Q = \frac{f_o}{bandwidth}$$

Parts of a Transducer

- Backing (damping) block – layered on back of PZT
  - Absorbs backward directed or stray U/S waves in housing
  - Dampens the PZT vibration to produce a pulse with short spatial pulse length (i.e. limits the vibration of the PZT element(s) to a small # cycles)
  - Transducer Q-factor – affect imaging applications
- Spatial pulse length = # cycles times wavelength
- Dampening of the vibration is known as "ring-down" and determines U/S bandwidth (range of frequencies)

$$\text{low Q transducer} \Rightarrow \text{heavy damping} \Rightarrow \text{short spatial pulse length, broad bandwidth}$$

  - Ex: high spatial resolution applications

$$\text{high Q transducer} \Rightarrow \text{little damping} \Rightarrow \text{long spatial pulse length, narrow bandwidth}$$

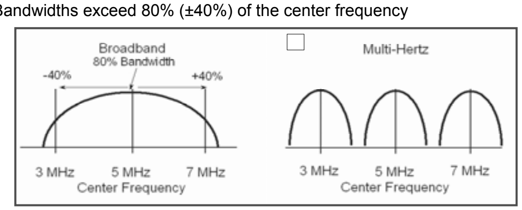
  - Ex: Doppler application where velocity info preservation is required

23

Ultrasound Transducers

Parts of a Transducer

- Broad-bandwidth, "multi-frequency" transducers
  - Adjust center frequency during transmit mode
  - Intricate machining of the PZT material (acoustic properties are closer to tissue)
  - Bandwidths exceed 80% (±40%) of the center frequency



  - Multi-Hertz operation indicates transducer is sensitive to a broad bandwidth in receive mode and the digital signal is subsequently processed to a selected bandwidth

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 488.

24

Ultrasound Transducers

Parts of a Transducer

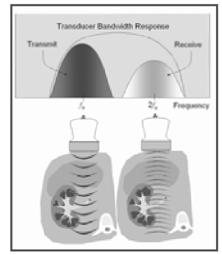
- Typically medical ultrasound is done with broad bandwidth transducers.
  - Pulses have a specific frequency content (bandwidth) and length
  - Pulses contain 2-3 wave cycles
  - Shorter pulses are possible when imaging at high frequencies (shorter period & λ); shortening a pulse also results in a wider or broader bandwidth
- Broad-bandwidth, “multi-frequency” transducers
  - Benefits of broadband transducers
    - One transducer to operate at multiple center frequencies
    - Smaller (shorter) pulses
    - Harmonic imaging

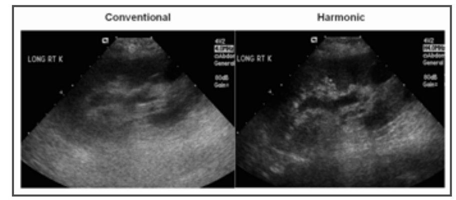
25

Ultrasound Transducers

Parts of a Transducer

- Broad-bandwidth, “multi-frequency” transducers
  - Example – harmonic imaging
    - Transmit – low frequency U/S pulses; receive – echoes of higher frequencies (frequency of echoes are multiples of the transmitted center frequency)
      - Higher frequency echoes result from U/S pulse interactions with contrast agents and tissue
    - Benefits of harmonic imaging – greater depth penetration, noise and clutter removal, improved lateral spatial resolution





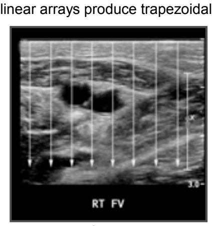
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 519.

26

Ultrasound Transducers

Parts of a Transducer

- Transducer Arrays – 128 to 512 individual PZT elements; width is typically less than ½ λ; length is several mm
- Transducer array modes of activation (transmit/receive modes)
  - Linear (or curvilinear) array transducers
    - 256 – 512 elements (physically these are largest transducer assemblies)
    - Simultaneous transmit of ~20 adjacent elements producing an effective transducer width
    - Echoes detected with all elements
    - Linear arrays produces rectangular field of view (FOV)
    - Curvilinear arrays produce trapezoidal FOV



c.f. Scherzinger & Stamm. AAPM/RSNA Web Modules. Ultrasound Concepts and Transducers. Section VI.C.

27

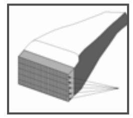
Ultrasound Transducers

Parts of a Transducer

- Transducer Arrays – 128 to 512 individual PZT elements; width is typically less than ½ λ; length is several mm
- Transducer array modes of activation (transmit/receive modes)
  - Phased array
    - 64 – 128 elements (smaller than linear transducer)
    - Steering or focusing is accomplished by activating all the elements nearly (but not exactly) simultaneously
      - Delays in the electronic excitation of individual crystal elements result in phase shifts in the emitted ultrasound pulses
      - By taking advantage of the wave interference that results, the beam can be steered in the desired direction
    - Image acquired without moving the transducer
    - Small face of the transducer allows for imaging through intercostal regions and in other areas where access to deep tissue is limited

28

Ultrasound Transducers



Parts of a Transducer

- Transducer Arrays – 128 to 512 individual PZT elements; width is typically less than ½ λ; length is several mm
- Transducer array modes of activation (transmit/receive modes)
  - Matrix transducers – 2D matrix of elements
    - Simultaneous 2D imaging in two orthogonal planes or oblique plane
    - 3D and 4D imaging

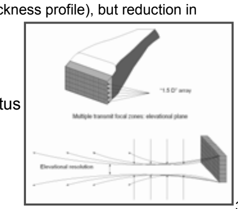
c.f. Scherzinger & Stamm. AAPM/RSNA Web Modules. Ultrasound Concepts and Transducers. Section VI.C.

29

Ultrasound Transducers

Parts of a Transducer

- Transducer Arrays – 128 to 512 individual PZT elements; width is typically less than ½ λ; length is several mm
- Transducer array modes of activation (transmit/receive modes)
  - Annular arrays
    - Nested concentric circles
    - Beam steering by mechanical rotation of xstals in housing – problematic, therefore, not commonly used
  - 1.5D array transducers
    - 1.5D transducers – multiple linear arrays that steer and focus the beam in the elevational direction; focusing achieved by phased excitation from outer to inner arrays; improved elevational resolution (slice thickness profile), but reduction in frame rate
- Specialty transducers
  - Endovaginal transducers – pelvic region and fetus
  - Endorectal transducers – prostate
  - Transesophageal transducers – heart
  - Intravascular transducers – blood vessels



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 500.

30

Ultrasound Transducers

Parts of a Transducer

- Matching Layer
  - Helps eliminate strong echoes (reflections) between PZT and tissue (b/c of large ΔZ)
  - Without matching layer, similar to reflective surface echoes between tissue and lung
  - Better transmission of sound from the transducer to tissue
  - Ideal matching layer thickness is ¼ λ of the U/S beam
  - Additional matching layer – acoustic coupling gel

c.f. Scherzinger & Stamm. AAPM/RSNA Web Modules. Ultrasound Concepts and Transducers. Section III: Impedance.

31

Ultrasound Beam Properties and Image Quality

32

Ultrasound Beam Properties

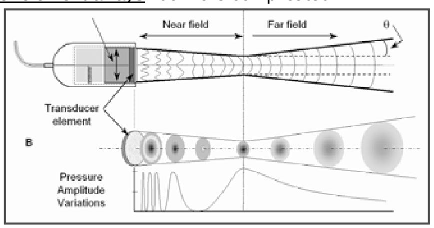
Two distinct beam patterns:

- The U/S beam converges out to a distance specified by geometry and frequency (near field)
- The U/S beam diverges beyond that point (far field)

Near field (also known as the Fresnel Zone)

- *For a single, unfocused transducer*: length of the near field is determined by the diameter of the transducer and the frequency of the sound emitted
- *For multiple transducer element arrays*: it's more complicated!

$$\text{Near Field Length} = \frac{d^2}{4\lambda} = \frac{r^2}{\lambda}$$

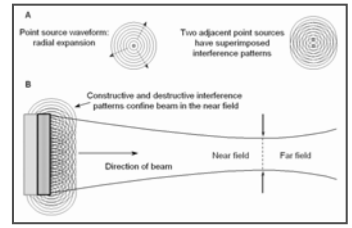


c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 491.

Ultrasound Beam Properties

Huygen's principle

- Infinite number of point sources with radial emission, causes multiple constructive and destructive interference patterns



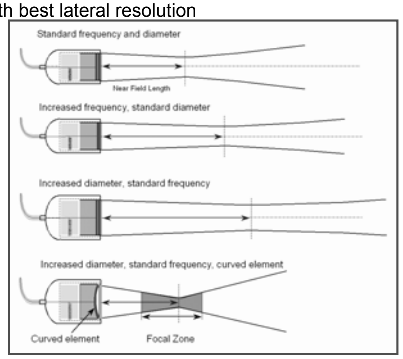
- U/S beam intensity varies from maximum to minimum to maximum from the transducer to the through the Fresnel Zone

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 491.

Ultrasound Beam Properties

Focal Zone

- Region over which the width of the U/S beam is less than two times the width at the focal distance
- Area with best lateral resolution



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 492.

Ultrasound Beam Properties

Far field (also known as the Fraunhofer zone)

- The point past which the beam diverges
- Less beam divergence with high-frequency, large-diameter transducers
- The angle of divergence in the far field can be calculated using the effective diameter of the transducer (d)

$$\sin\theta = 1.22\frac{\lambda}{d}$$

- U/S intensity decreases monotonically with distance

Ultrasound Beam Properties

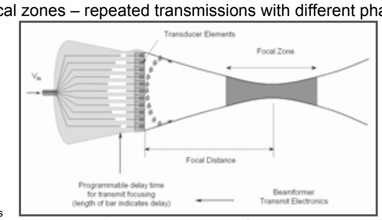
Beam formation

- Control over the transmission of U/S pulses from individual elements in an array (by minor changes in phase difference b/w adjacent elements) change the constructive and destructive interference pattern and ultimately the beam profile
  - Used to steer and focus the beam
  - Done in both transmit and receive modes

Ultrasound Beam Properties

Transmit focusing

- Traditionally, focusing was achieved by curved lens – not possible with multi-crystal structure
- Modern transducers have selectable focal distances – apply specific timing delays b/w transducer elements (results in phase differences b/w adjacent element pulses) that cause the beam to converge at a specified distance
  - Shallow focal spot distance – fire outer elements in the array before the inner elements
  - Greater focal spot distance – reduce time delay (still fire outer to inner elements)
  - Multi-focal zones – repeated transmissions with different phase timing

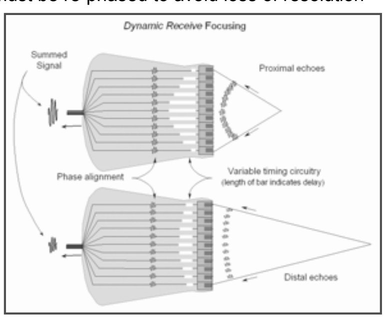


c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 494.

Ultrasound Beam Properties

Receive focusing

- Echoes received at edge of element arrays travel slightly longer distances than echoes received at the center of the array (particularly at shallow depths)
- Signals must be re-phased to avoid loss of resolution

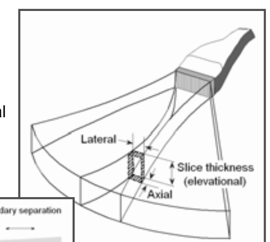


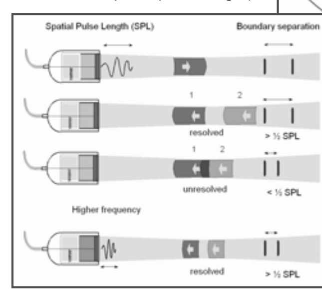
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 495.

Ultrasound Image Quality

Spatial Resolution – 3 distinct measures

- Axial – depth resolution
  - Returning echoes distinct w/out overlap
  - Minimal distance b/w objects is ½ the spatial pulse length
  - Depends on frequency & damping factor (which both determine spatial pulse length)



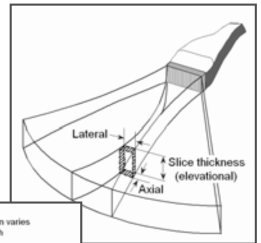


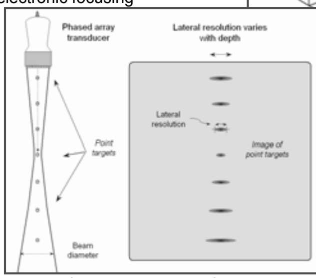
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 497, 498.

Ultrasound Image Quality

Spatial Resolution – 3 distinct measures

- Axial
- Lateral – resolution perpendicular to the beam path
  - Depends on beam diameter (since beam diameter varies w/ depth, the lateral resolution varies w/depth) and mechanical/electronic focusing





c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 497, 499.

41

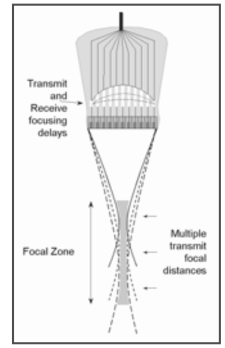
Ultrasound Image Quality

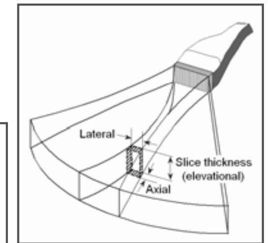
Spatial Resolution – 3 distinct measures

- Axial
- Lateral – resolution perpendicular to the beam path

Multiple transmit/receive focal zones (improves lateral resolution, increased image rate & frame rate)

Focal Zone – region over which the width of the U/S beam is less than two times the width at the focal distance





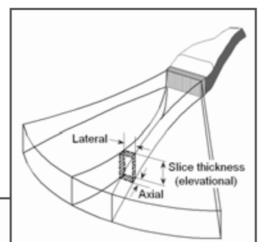
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 497, 499.

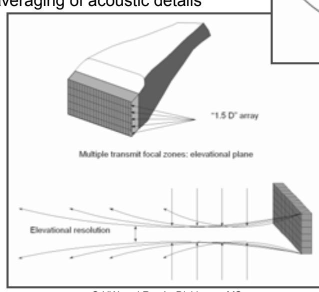
42

Ultrasound Image Quality

Spatial Resolution – 3 distinct measures

- Axial
- Lateral
- Elevational (slice thickness)
  - Typically worst resolution for array transducers
  - Volume averaging of acoustic details





c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 497, 498.

43

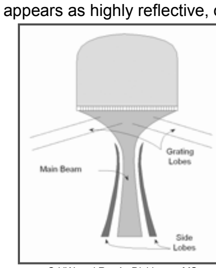
Ultrasound Image Quality

Side lobes

- Off-axis energy emission directed away from the main beam
  - Unavoidable; remapped along the main beam in receive mode
  - Low Q (wide broad bandwidth) – reduces emission of side lobe energy

Grating lobes

- Energy emitted far off-axis (large angles) from the main beam by multi-element arrays
  - Consequence of a non-continuous transducer surface
  - Low amplitude; appears as highly reflective, off-axis objects in the main beam



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 496.

44

Ultrasound Image Quality

Distance, area, and volume measurements

- Possible b/c speed of sound in soft tissue known to ±1% (1540 m s^{-1} ± 15 m s^{-1})
- Calibration based on round-trip time of pulse and echo
- Measurements in direction of U/S beam more reliable as the resolution is best in the axial direction
- Measurements in the lateral direction are subject to more blur depending on depth

Anechoic object imaging

- Web Mod, Image Quality-Artifacts-Doppler, Section III.A.

Dead Zone

- Web Mod, Image Quality-Artifacts-Doppler, Section III.B.

Ultrasound Image Quality

Contrast and noise

- Depends on Z differences, density and size of scatterers, and signal loss with depth
- CNR determines detectibility of subtle anatomy
- Noise mainly generated from electronic amplifiers; noise also increased at depth by using TGC
- Image processing to increase CNR (temporal or spatial averaging); trade-offs lower frame rates and/or poorer spatial resolution

Artifacts (Web Mod, Image Quality-Artifacts-Doppler)

- Refraction – misplaced anatomy in the image (Section IV.E.)
- Shadowing and enhancement
- Reverberation (Section IV.C.)
- Speed displacement (Section IV.G.)
- Side lobes & grating lobes (Section IV.F.)
- Multipath reflections & mirror image (Section IV.D.)
- Slice thickness (Section IV.A.)

Ultrasound Topics NOT Discussed

Please review 2009 U/S Lecture 3 by Dr. Kanal

- Doppler
- Power doppler
- Color doppler
- Ultrasound contrast agents
- Compound imaging
- ** Harmonic imaging
- 3D and 4D (time-dependent) imaging
- ** Artifacts
- Safety and bioeffects
  - Mechanisms for producing bioeffects – heating, cavitation, direct mechanical
  - Acoustic power
  - Intensity measures of U/S energy deposition
  - Thermal indices and mechanical indices
  - Pregnant patient and pediatric protocols