A stack of five smooth, grey stones is balanced on a beach of pebbles. A white paper overlay with four silver fasteners is positioned in the center, containing the text 'Ultrasound Transducers' and 'Chapter 2'. The background shows a blurred ocean and sky.

# Ultrasound Transducers

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## Chapter 2

# The Piezoelectric Element

- A **piezoelectric** material is an element that generates electricity when pressure is applied to it and that changes shape when electricity is applied to it.
- The piezoelectric material is the material that produces diagnostic ultrasound. Piezoelectric materials may be naturally occurring, such as quartz and tourmaline, or man-made.
- The piezoelectric material that is commonly used in current ultrasound transducers is a manmade ceramic called **lead zirconate titanate (PZT)**.
- The PZT may also be referred to as the **crystal**, the **element**, or simply, the **transducer**.

# The Piezoelectric Element

- For material to gain piezoelectric properties, it must be heated to the **Curie point** and **polarized**
  - Created by exposing material to strong magnetic field while being heated to a substantial temperature (325-365° C)
  - This causes magnetically charged molecules, called dipoles, that are located within the material, to align themselves in relation to the magnetic field
- **Depolarization** occurs when the PZT is heated above the Curie point and the piezoelectric properties are destroyed

# The Piezoelectric Element

- Unfortunately, once a ceramic is taken to its Curie point, it must never return to that temperature again or the material will lose its piezoelectric properties forever
- For this reason, ultrasound transducers are never heat-sterilized
  - Use cold-sterilizing solutions instead (Cidex)
  - Sonographer needs to wear PPE and be aware of MSDS guidelines
- Newer method of HLD uses hydrogen peroxide solution to disinfect transducers (Tropon)

# Production of Sound

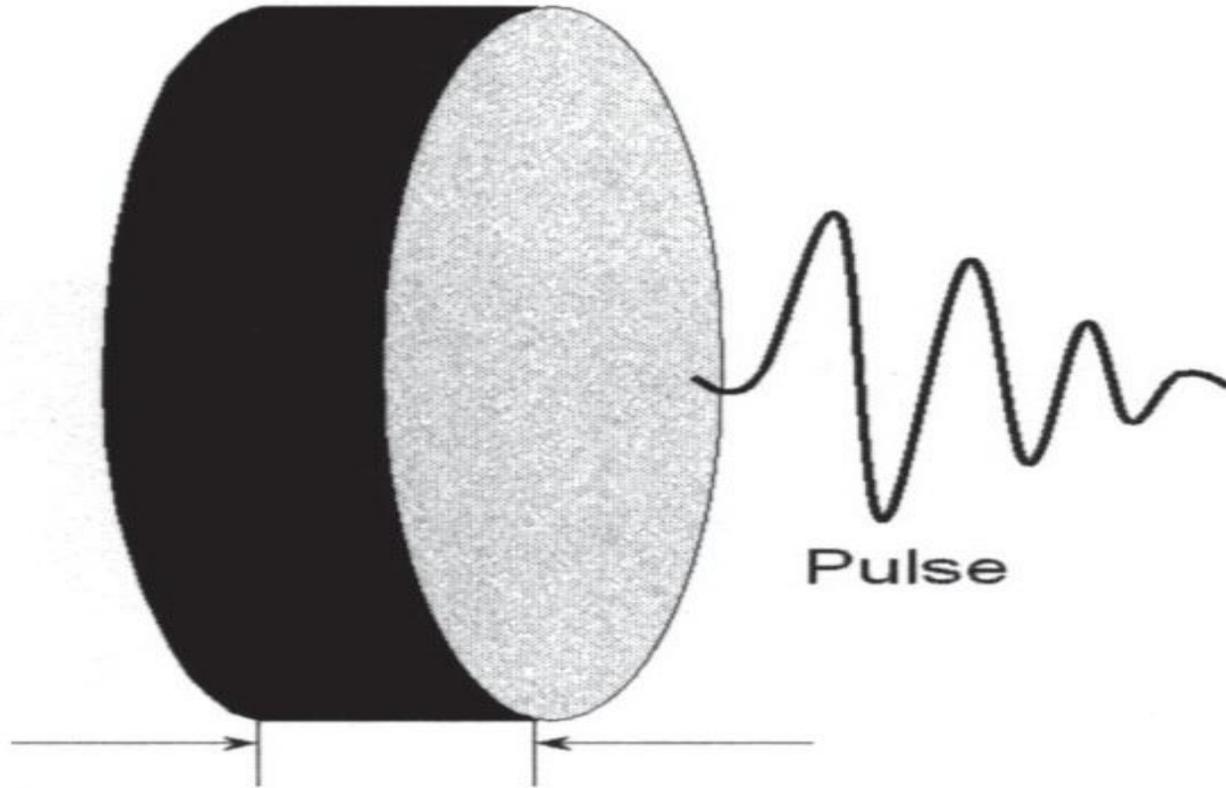
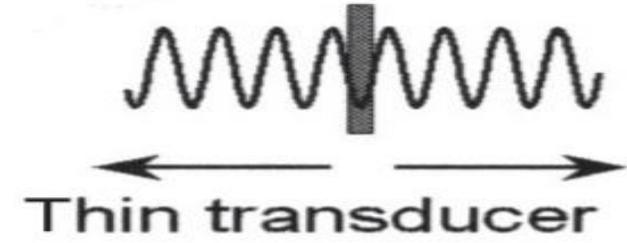
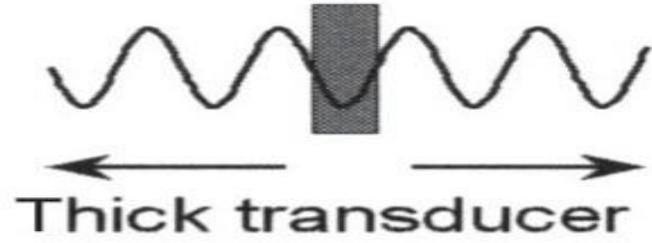
- One or more piezoelectric elements are attached to an electric wire in the transducer
- Applying electricity to the element causes it to resonate, or alternatively expand and contract
- The **frequency**, or rate at which the material resonates is related to two factors:
  1. Thickness of the piezoelectric element
  2. Propagation speed of the element itself

# Production of Sound

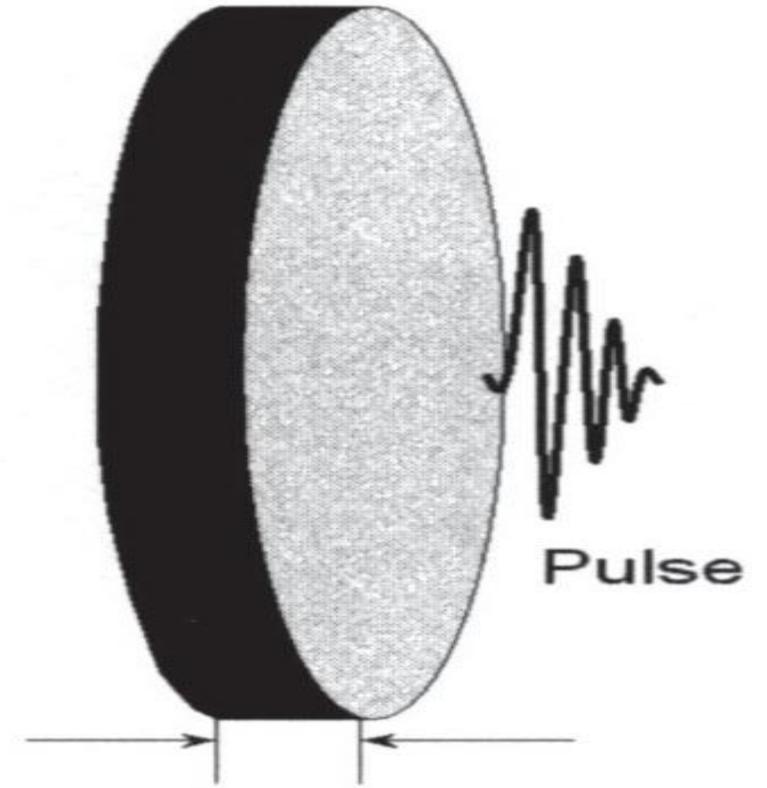
$$\text{Frequency } (f) = \frac{\text{Propagation speed } (c)}{2 \times \text{thickness}}$$

- In pulsed-wave operation, the thickness of the element is the primary determinant of the resonating frequency of the transducer
- A thicker element will produce a lower frequency, whereas a thinner element will produce a higher frequency
- Sonographer cannot adjust the resonating frequency of a piezoelectric element
- Frequency is  $\frac{1}{2}$  wavelength ( $\lambda$ ) thick

$f_0$  is determined by the transducer thickness equal to  $\frac{1}{2} \lambda$



Low frequency



High frequency

# Production of Sound

- The resonating element produces a pressure wave
- This wave consists of alternating waves of high pressure and low pressure, or compressions and rarefactions, respectively
- The **resonating frequency**, also known as the **center** or **operating frequency**, of a medical diagnostic ultrasound transducer is typically between 2 and 15 MHz
- This expanding and contracting of the element produces a propagating ultrasound wave that travels into the human body

# Production of Sound

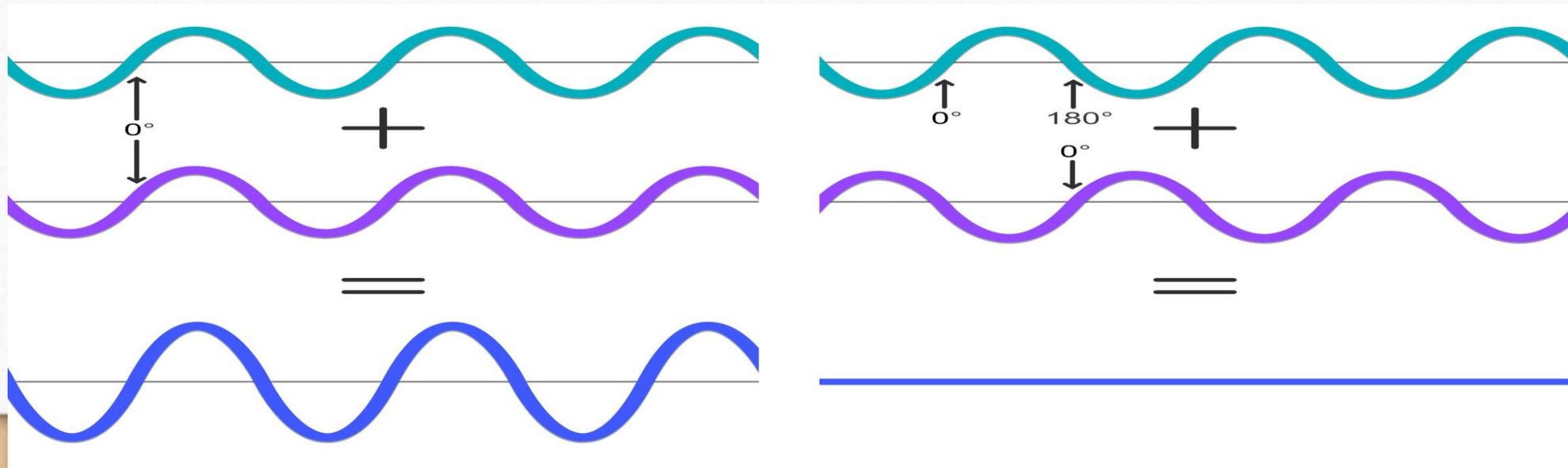
- Many ultrasound transducers use pulsed sound. Piezoelectric elements can both send and receive ultrasound but not at the same time
- That is, a single element can emit sound, but it must wait for that sound to return before it can send out the next pulse

# Production of Sound

- The machine must time how long it takes for a pulse of sound to reach the reflector and come back in order to appropriately display anatomy on the monitor
- If the transducer sends out a pulse before it receives the last one, it is unable to recognize where the echo originated, and therefore, cannot display it correctly on the monitor
- This is referred to as **depth ambiguity** or **range ambiguity**

# Huygen's Principle

- Sound travels as a wave and often these wave interact and cause interference
  - **In-phase waves** will undergo **constructive** interference
  - **Out-of-phase waves** will undergo **destructive** interference

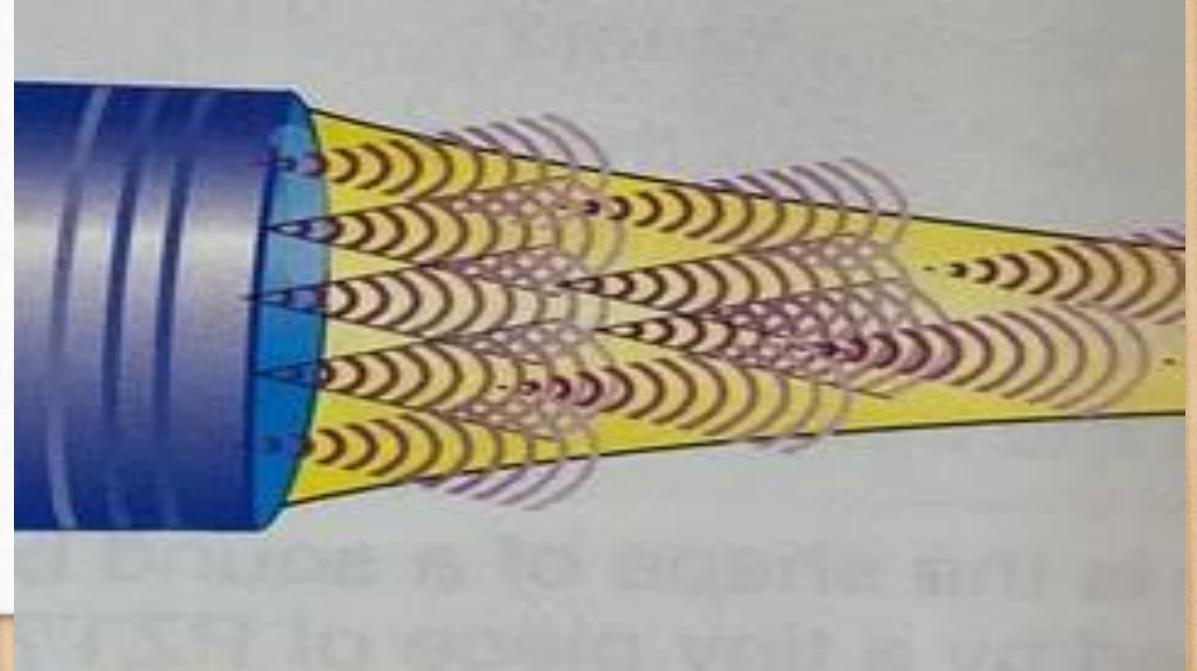
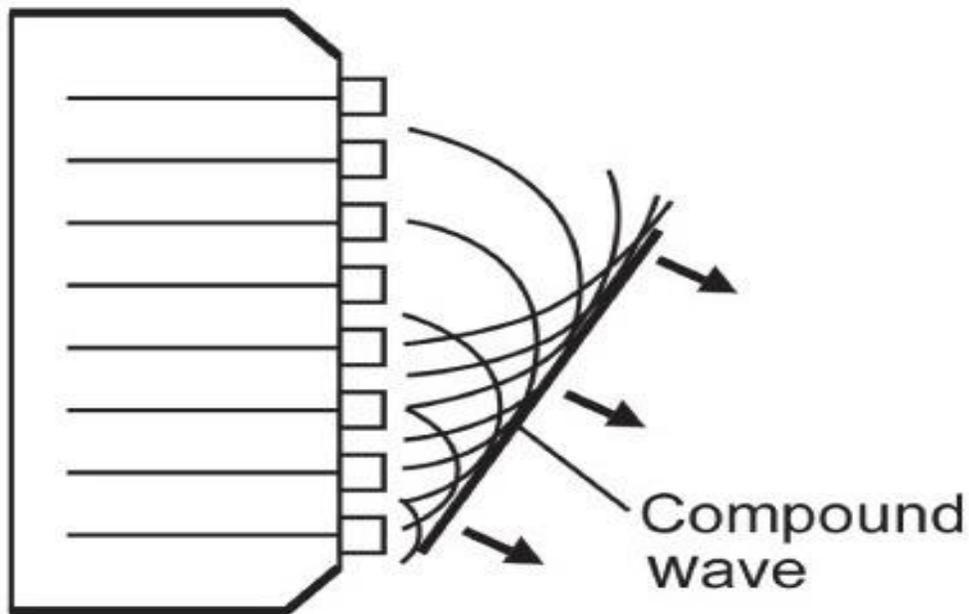


# Huygen's Principle

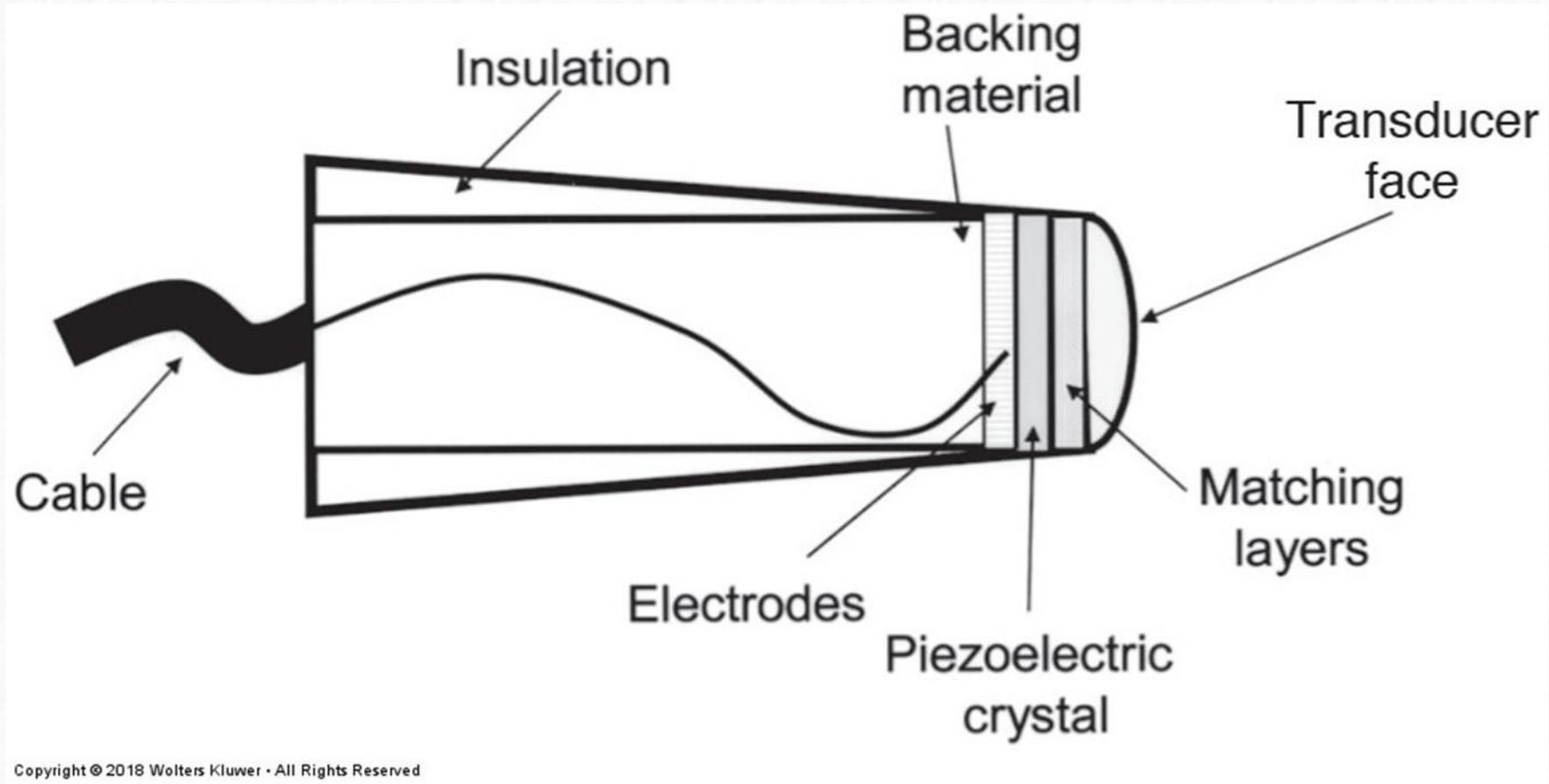
- **Huygen's Principle** explains how one large sound wave is created from many tiny, distinct sound sources
- The surface of the transducer is made up of many tiny spots that produce sound
  - Each tiny spot will produce a wavelet and these wavelets interfere constructively or destructively
  - This process of multiple wavelets (tiny v-shaped waves) interfering is what creates an actual sound wave that travels perpendicular to the wavefront

# Huygen's Principle

- Sound waves develop into an “hourglass shape” based off Huygen's Principle where multiple tiny sound wavelets interfere and create one larger sound wave



# Construction of the Transducer



# Transducer Housing and Wire

- Metal or plastic
- Protects internal components from damage
- A crack in the transducer housing poses the highest risk for electrical shock to either the sonographer or the patient
  - Insulation (cork or rubber) is used to protect the user and the patient
  - Thin metallic barrier lines the inside of the housing to prevent electrical signal and noise from causing interference on the images

# Transducer Housing and Wire

- Modern transducers contain more than a hundred individual transducer elements, each of which is supplied with electrical energy via a wire
- This wire also transmits the received echo amplitude information to the machine for processing
- A flexible sheathed connector allows flexibility of the cord and prevents damage to the wire where it connects to the transducer

# Matching Layer

- It is important to remember that the bigger the impedance mismatch, the stronger the reflection
  - The more sound that is reflected off the skin, the less sound there is to be transmitted into the tissue
- The impedance of the piezoelectric element is significantly different from that of the patient's skin
  - Impedance PZT is 20 times greater than impedance of skin

# Matching Layer

- If no action were taken, this large mismatch would prevent almost all the sound from entering the patient
  - 80% of the sound would be reflected and only 20% would be transmitted into the patient
- Therefore, the transducer is equipped with a **matching layer** that lies between the piezoelectric element and the patient's skin

# Matching Layer

- The purpose of the matching layer is to step down the impedance from that of the element to that of the patient's skin
  - Improve efficiency of transmitting sound by lowering the impedance mismatch
  - The additional use of ultrasound gel, or coupling medium, aides to further enhance the transmission of sound

# Matching Layer

- Impedances:
  - $\text{PZT} > \text{matching layer} > \text{gel} > \text{skin}$
- The matching layer also protects the active element
- Matching layer is  $\frac{1}{4}$  wavelength ( $\lambda$ ) thick

# Backing Material and Damping

- Also known as “damping element”
- Made of epoxy resin with tungsten filaments
- When electrical spike excites PZT
  - Backing material restricts extent of PZT deforming
- Emitted pulse is dampened
  - Short in duration and length
    - **Enhances axial resolution**
    - **Decreases spatial pulse length**

# Other Effects of Damping

- With damping material PZT ringing will be substantially reduced
- Emitted pulse is short in both:
  - Length
  - Duration

} Short pulses enhance axial resolution
- Consequences of using damping material:
  1. Decreased sensitivity
  2. Wide bandwidth
  3. Low quality factor

# Other Effects of Damping

- Sensitivity is the ability to detect weak returning echoes
- Using damping material **decreases the sensitivity** of the system
  - Transducers less able to convert low-level reflection into electrical signal during reception
- Reduces vibration during transmission as well as reception
  - This is undesirable
    - Transducers are less responsive

# Other Effects of Damping

- **Resonant frequency** – the single frequency in which the crystal vibrates freely for a long time
  - Also called the **main** or **center frequency**
  - Resonant frequency is the label on our transducers (i.e. C5-1)
  - Using damping material prohibits the crystal from vibrating freely
    - Produces a “less pure” operating frequency by producing multiple frequencies as the PZT is being restricted

# Other Effects of Damping

- **Bandwidth** is the range of frequencies present
- Imaging transducers (PW) use damping material, and this creates a “wide bandwidth” or “broadband” that the transducer operates at
  - Short pulses with multiple frequencies contained within
- Non-imaging transducers (CW) do not have any damping material and therefore only operate at one frequency
  - Long pulse with only a single frequency

# Other Effects of Damping

- **Bandwidth**
- Units: Hertz (Hz)
- Bandwidth = maximum frequency – minimum frequency

# Other Effects of Damping

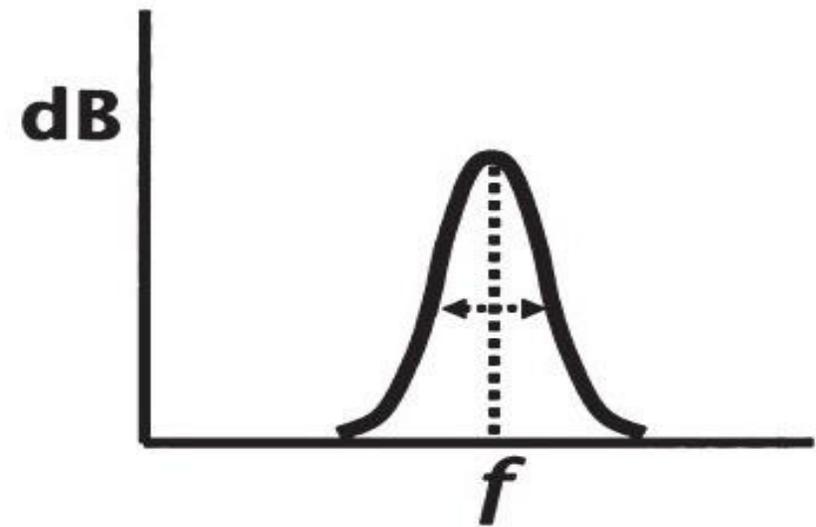
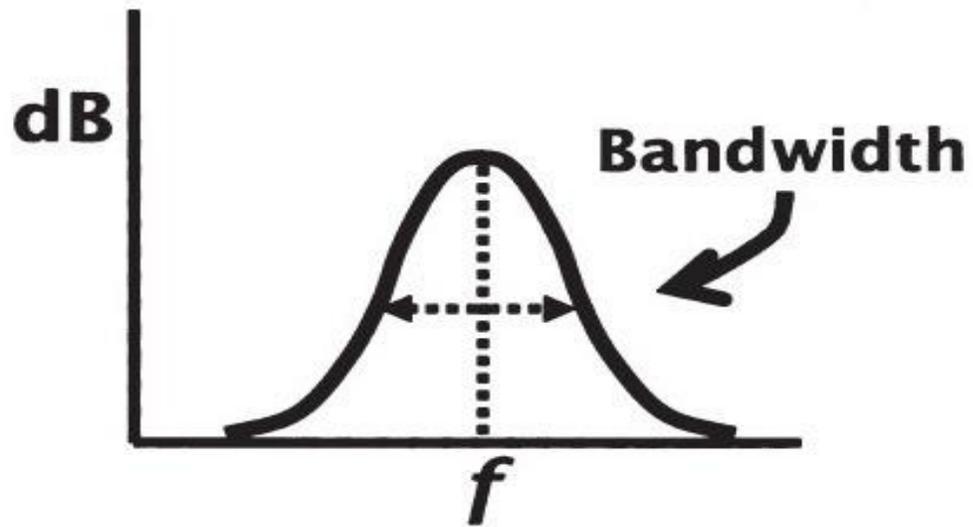
- **Quality factor (Q-factor)** defines the purity of the sound beam

$$\text{Q-factor} = \frac{\text{frequency}}{\text{bandwidth}}$$

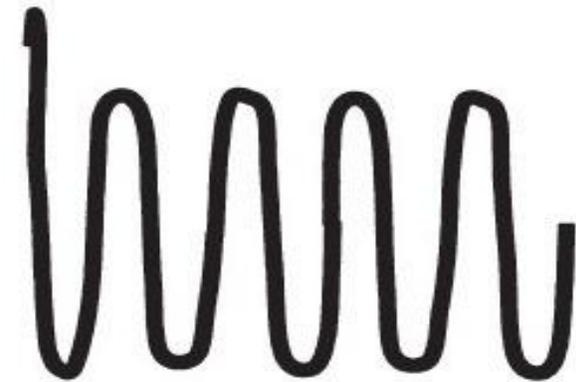
- PW transducers are considered **low Q-factor** because they contain damping material to shorten the pulse
- CW transducers are considered **high Q-factor** because they have a narrow bandwidth and contain no damping material

# Other Effects of Damping

- Although the “Q” in Q-factor indeed stands for “quality,” it is not the resolution of the image that is being referred to, but rather the purity of the beam
- Thus, when understanding quality factor, the question should be asked “How near to the actual operating frequency is the bandwidth?”



→  
Ultrasound pulse



→ Time

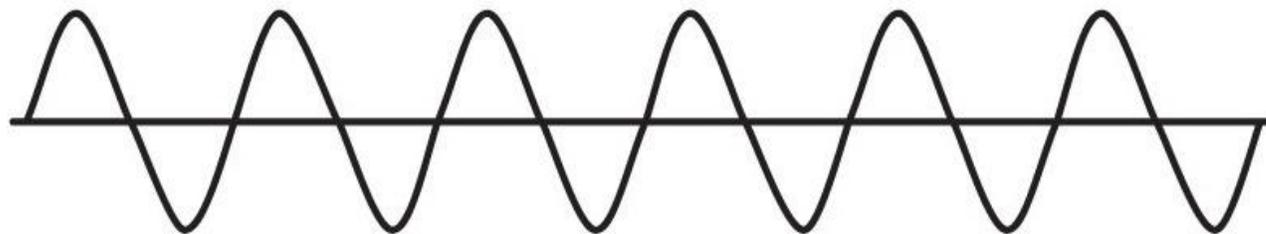
**As pulse length increases, the frequency spectrum narrows  
∴ Longer pulse length ⇒ narrower bandwidth ⇒ lower resolution**

Damping

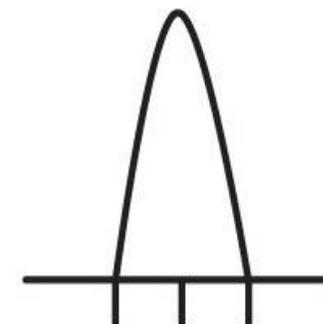
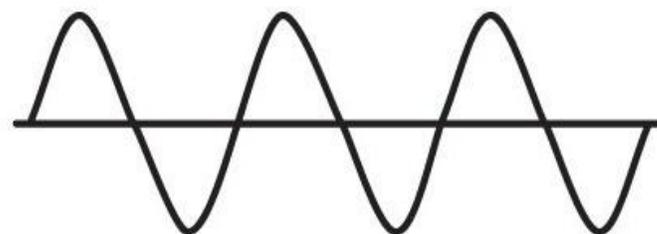
Pulse length

Bandwidth

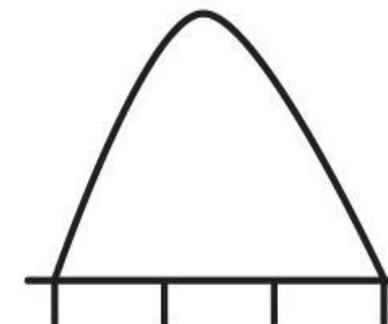
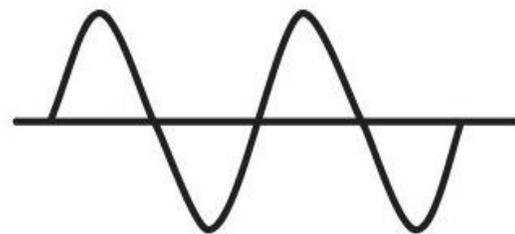
**A**



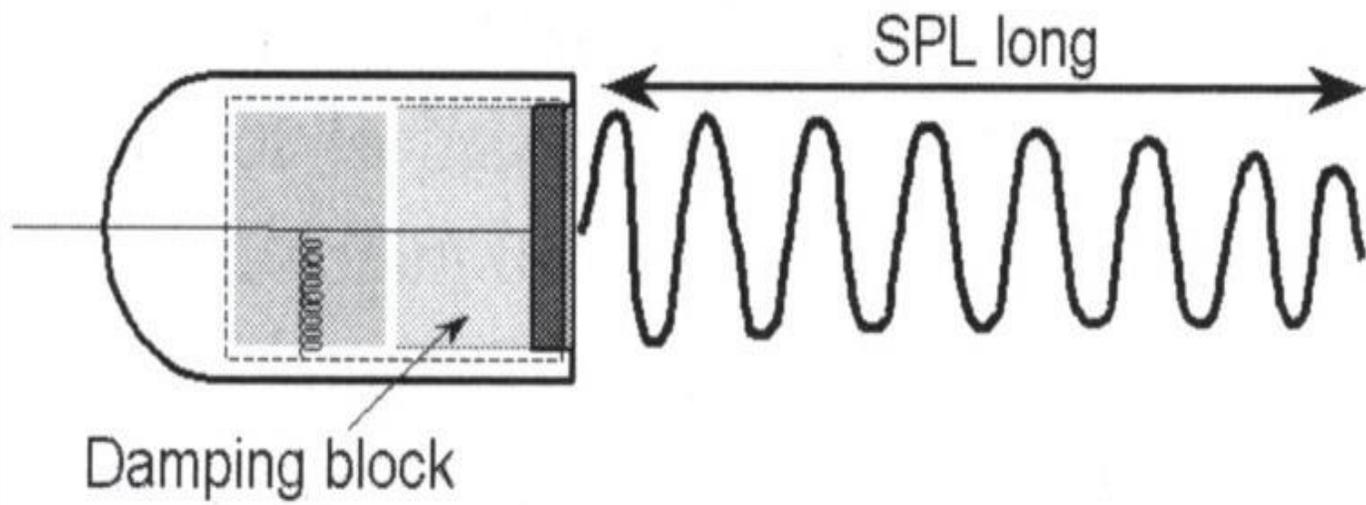
**B**



**C**



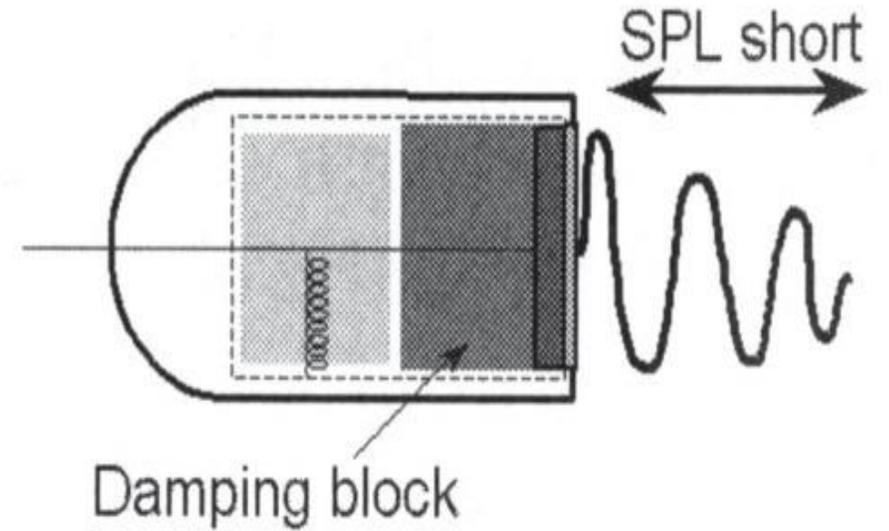
Light damping, high Q



**A**

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Heavy damping, low Q



**B**

# Real-time Scanning

- Modern ultrasound equipment utilizes **real-time**, or **automatic scanning**, to obtain diagnostic images of the body
- With real-time scanning, the transducer is responsible for sending out **scan lines** across a defined plane
- Images are produced when an ultrasound beam is swept across that plane
- Pulses of ultrasound are sent out and produce scan lines
- All the scan lines, when placed next to each other, form an image that is called a **frame**

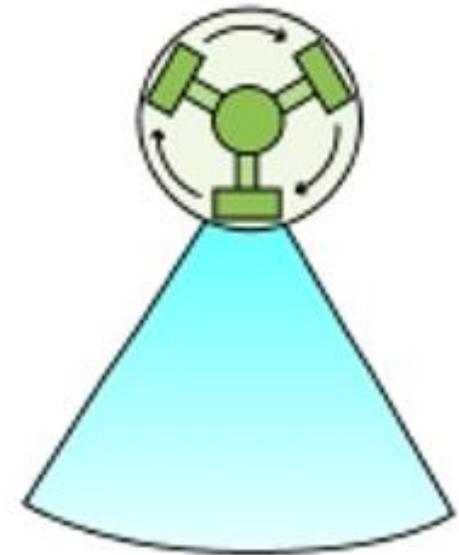
# Types of Transducers

- There are two methods of sending out scan lines to form an image using realtime:
  1. Mechanical scanning (via mechanical transducers)
  2. Electronic scanning (via electronic transducers)
- Both methods provide a means for sweeping the ultrasound beam through the tissue repeatedly and rapidly

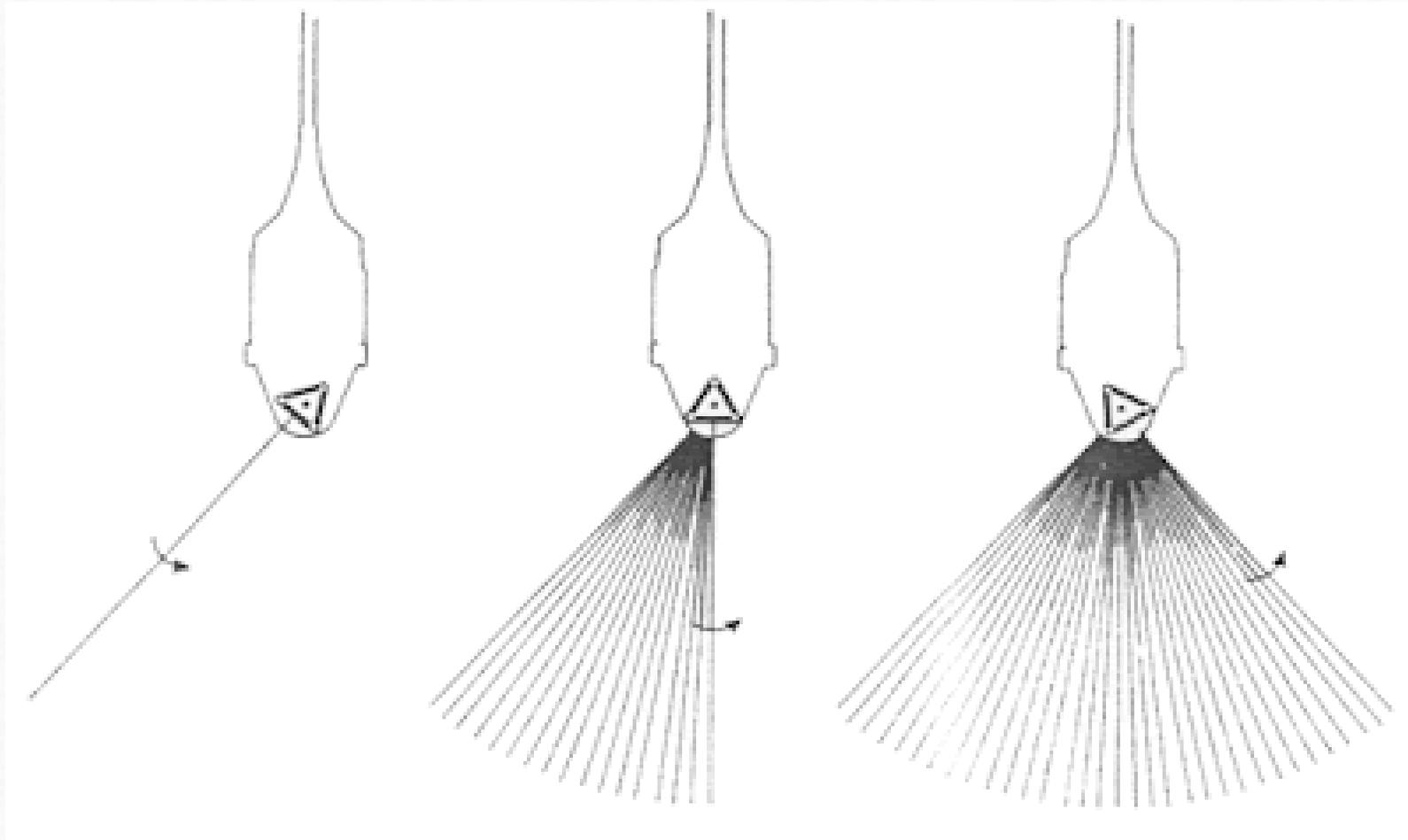
# Mechanical Transducers

- Largely obsolete and not used in today's sonography departments
- One or more piezoelectric elements connected to a motor, or a fixed element with a mirror connected to a motor
  - Motor steered the element, or mirror, to produce the scan lines that generated the image

Mechanical Sector Transducer



# Mechanical Transducer



# Mechanical Transducers

- Oil was used as a coupling medium to prevent air from forming within the housing
  - Air within the housing would hamper the transmission of the sound
- These transducers were *fixed frequency* and *fixed focus*
  - That is, in order to change the frequency or the location of the focal zone, one had to change the entire transducer
  - Fixed focusing aka – conventional or mechanical focusing

# Mechanical Transducers

- Focusing of the beam was achieved by either the shape of the element or the use of a lens
  - **Internal focusing** – curving active element 
  - **External focusing** – lens placed in front of the element 
- The major advantages of the mechanical transducer were that they were inexpensive and typically had a small **footprint**
- Unfortunately, they were fragile, and their mechanical elements were easily broken
- Today's equivalent is the 3D/4D transducer

# Mechanical Transducers

- What happens to your image if a crystal becomes damaged?
  - Most mechanical transducers only have one crystal. The entire image is lost if it becomes damaged



# Electronic Transducers

- Electronic scanning is performed with transducers that have multiple active elements
- Referred to as an **array**
  - An array is formed by taking a single slab of PZT and slicing it down into multiple sub elements
- Each sub element is connected to a wire, so it may fire independently
  - **Channel** – single PZT element, wire, electronics in the system

# Electronic Transducers

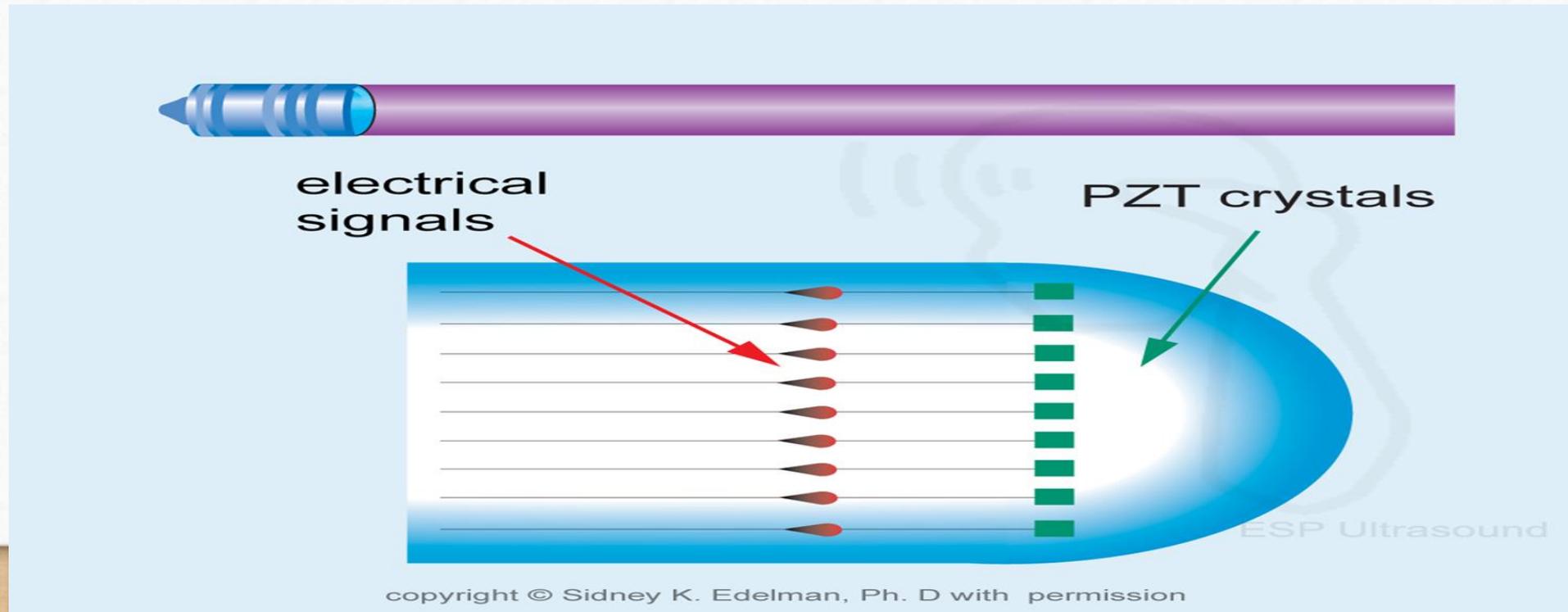
- The system can be selective in which PZT elements are activated
  - This will shape and steer the beam in any direction
- Does not rely on motors to move the crystals into position to create a scan line
- Multiple types of electronic transducers that produce many image shapes
- **PHASED ARRAY** - think “adjustable” and “multi-focus”

# Electronic Beam Steering

- Electronic steering “phasing”
  - Beams electronically transmitted in different directions without the use of moving parts
  - The system changes the timing of electrical signals that are sent to each crystal
  - Time delays result in a Slope being formed that creates the Steering

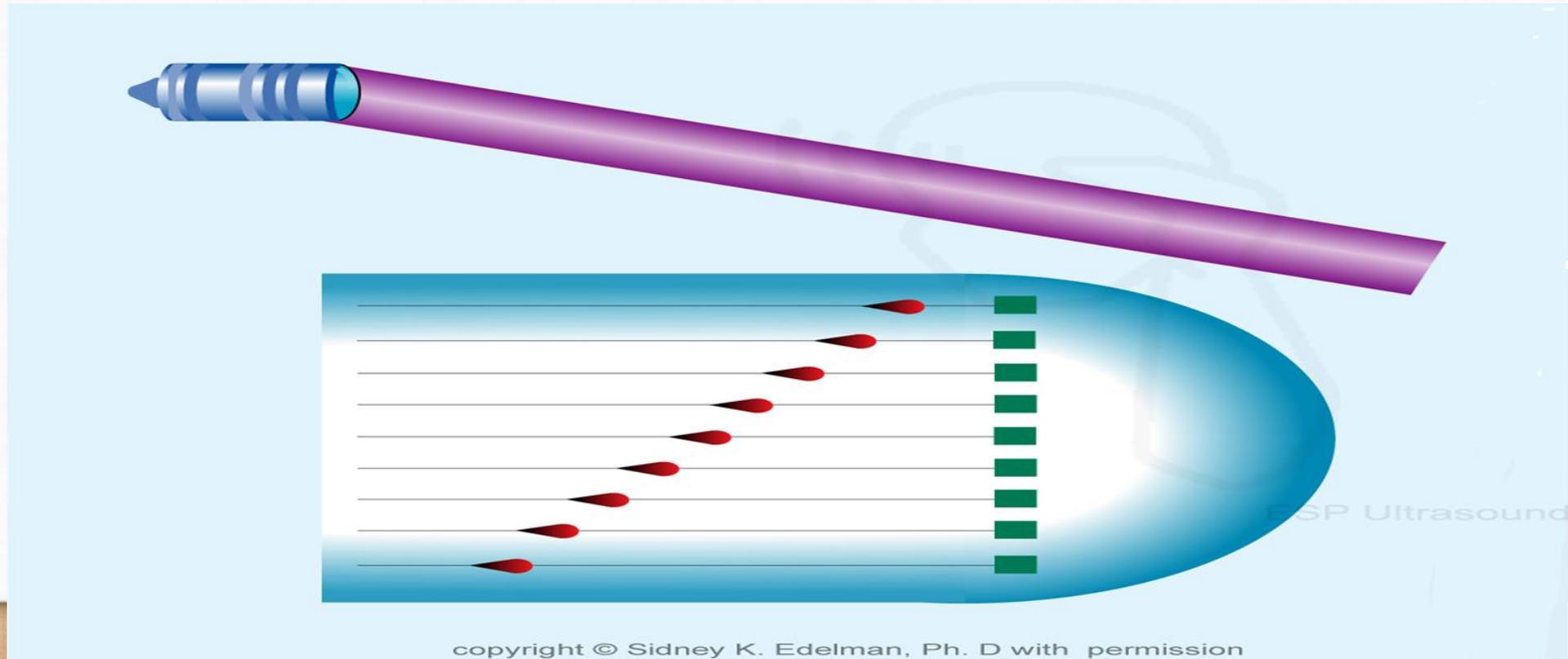
# Electronic Beam Steering

- If no steering is activated, all electrical signals will arrive at the crystals at the exact same time
  - Sound beam is directed straight ahead and not steered in any direction



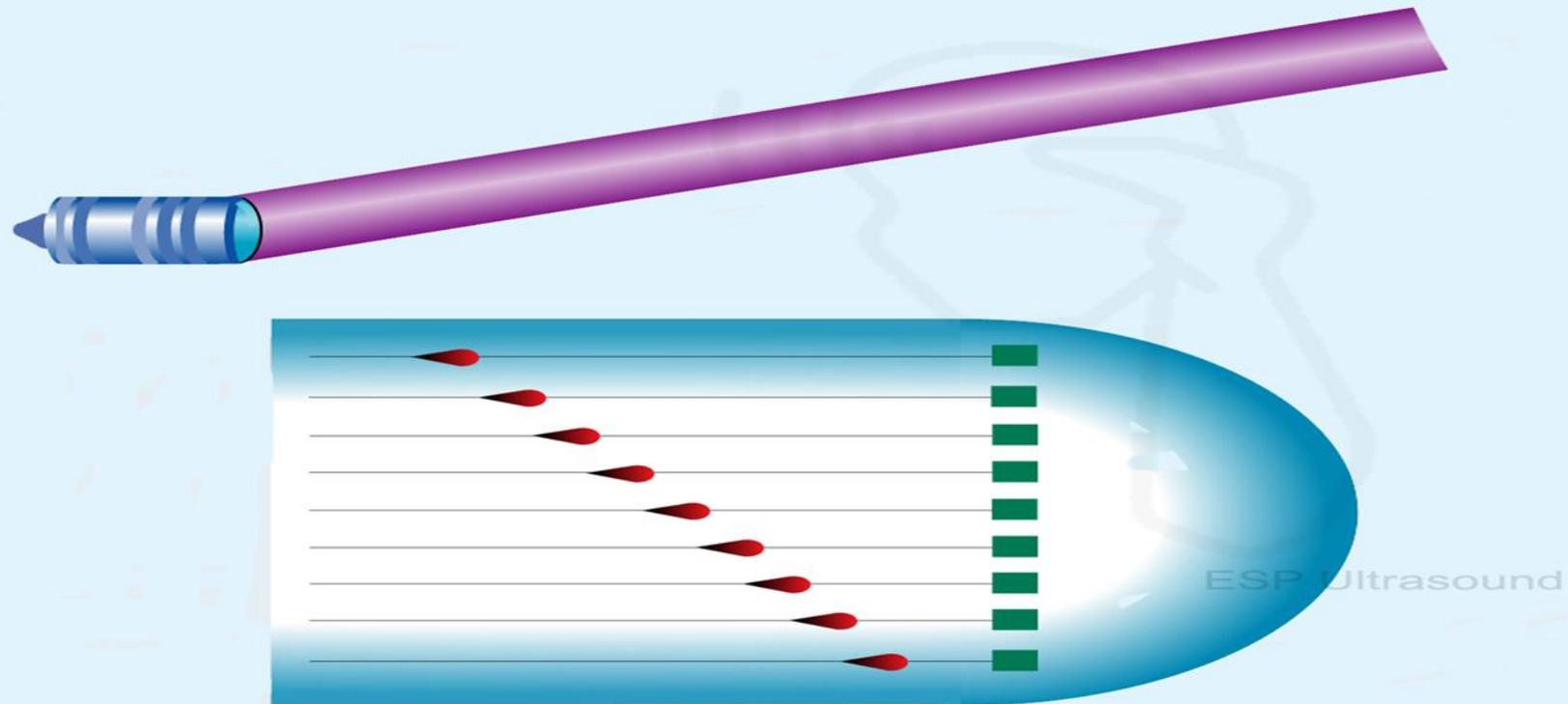
# Electronic Beam Steering

- Slope of the electrical spikes determines the direction of the steering



# Electronic Beam Steering

- Slope of the electrical spikes determines the direction of the steering



# Electronic Beam Steering

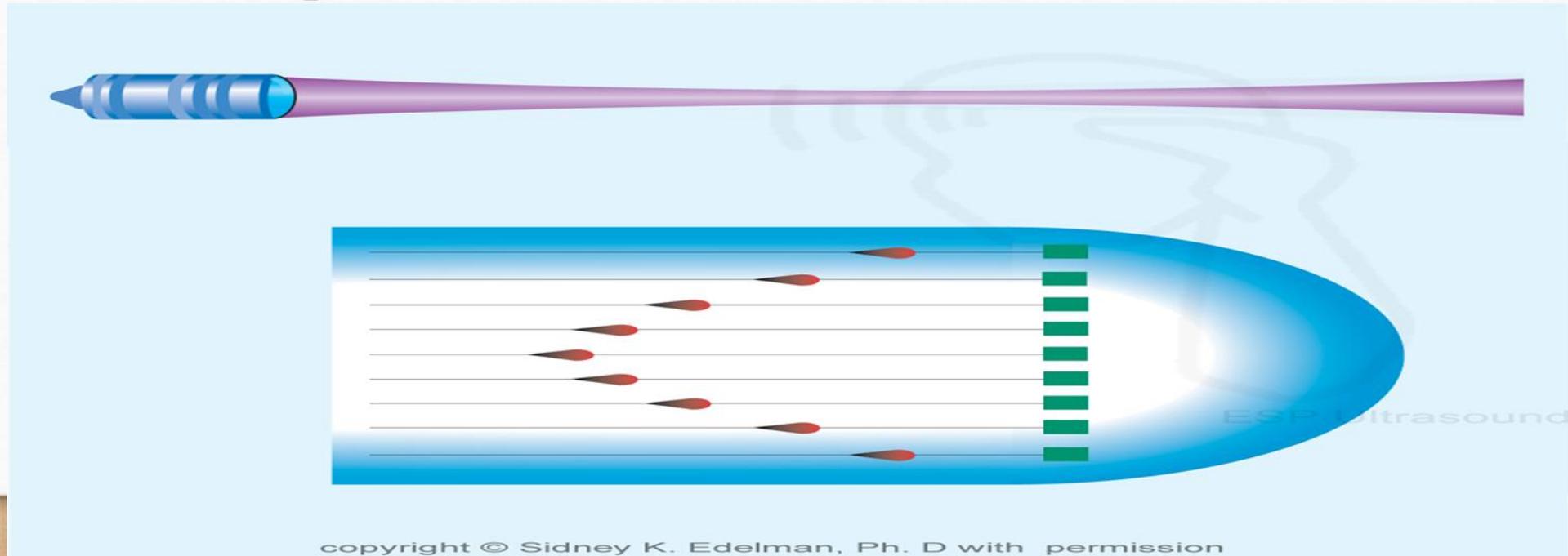
- Changes in the electrical excitation pattern are controlled by the beam former
  - Slight variations in the sloping will steer or sweep the beam in slightly different directions
    - This helps to create the sector/fan shaped images with our phased array transducers

# Electronic Beam Focusing

- Beam focusing (happens during TRANSMISSION)
  - Electronically focused by again changing the timing of electrical excitation pulses to each crystal
  - Sonographer can adjust the number and placement of focal zones which changes the excitation pattern
  - Curving of the excitation pattern creates Focusing
  - Phased array always means “adjustable” and “multi-focus”

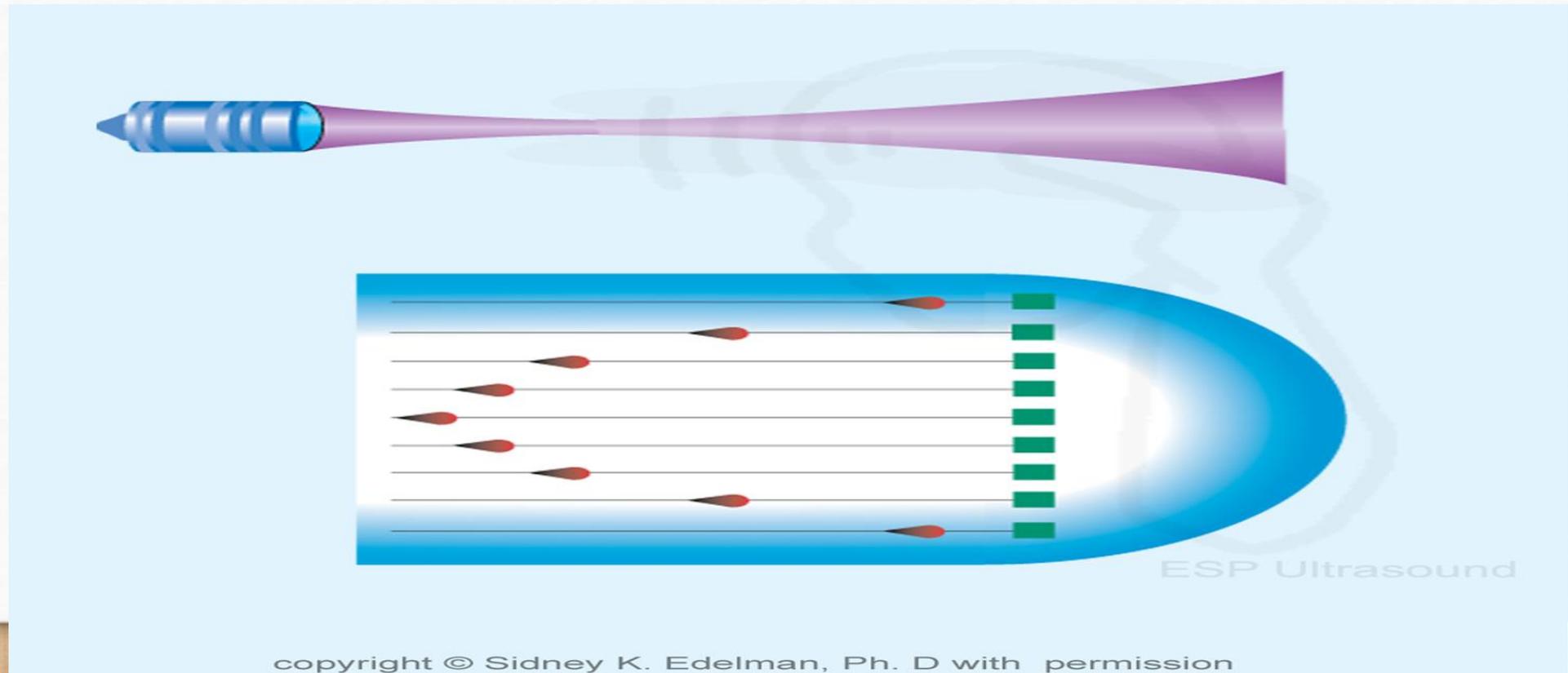
# Electronic Beam Focusing

- Transmit focusing
  - Beam is formed by exciting the outer crystals first, then working toward the middle
  - Curvature pattern creates a focused sound beam



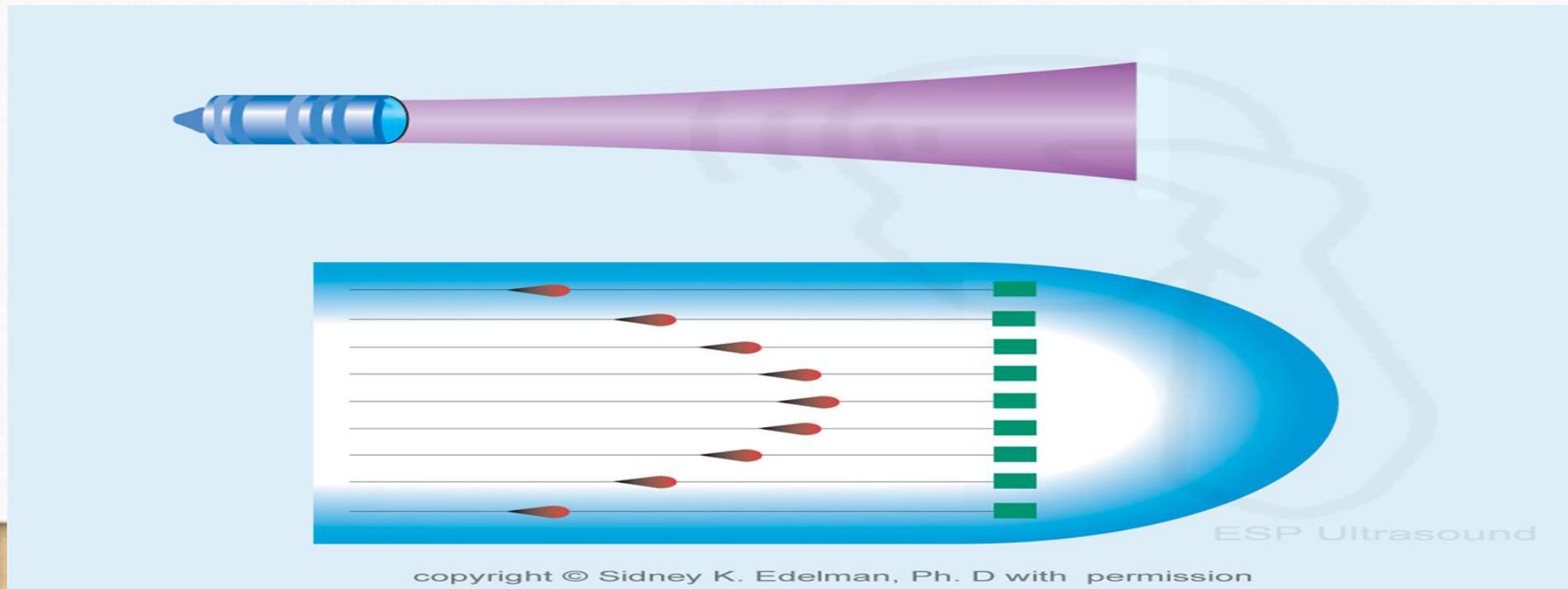
# Electronic Beam Focusing

- Moving the focal zones to the top of your screen will create a shallower focus



# Electronic Beam Focusing

- Convex or “D-shaped firing pattern” creates a defocused or divergent beam
  - Clinically irrelevant – poor image/no image produced



**Electronic Pattern**

**Sound Beam**

**Slope**

**Steering**

**Curvature**

**Focusing**

# Dynamic Receive Focusing

- Focusing may also occur during **reception**
  - When reflected sound arrives at transducer
    - Multiple elements along the front are excited
      - Creates electrical signals that return through the channels to the system's receiver

# Dynamic Receive Focusing

- Time delays of signals during reception
  - Creates more accurate image
  - Delays depend on depth at which reflection was created
    - Delay pattern change continuously as transducer “listens” for reflections
  - Allows focusing at many depths

# Linear Sequenced Array

- Linear Sequential Array
- Linear Sequenced Array
- Linear Array
- Linear Switched Array

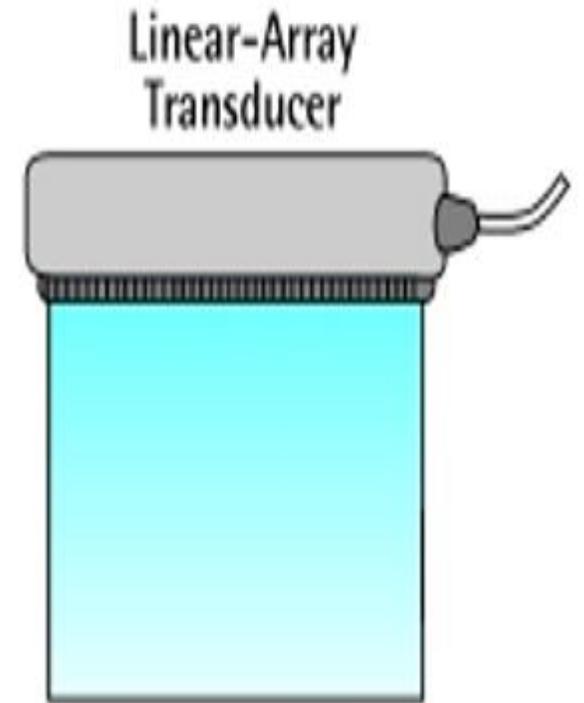


Used in vascular and  
small part imaging

- Produces a rectangular shaped image
  - The only transducer that creates an image the exact same size as the probe!

# Linear Sequenced Array

- With linear array transducers, all elements are arranged in a line, but only small group of elements are activated in a sequence
- Beam steering is not needed to produce the image; however, it can be used during Doppler exams or to create a vector image
  - Electronic steering
- Uses electronic focusing during transmit and dynamic receive focusing during reception

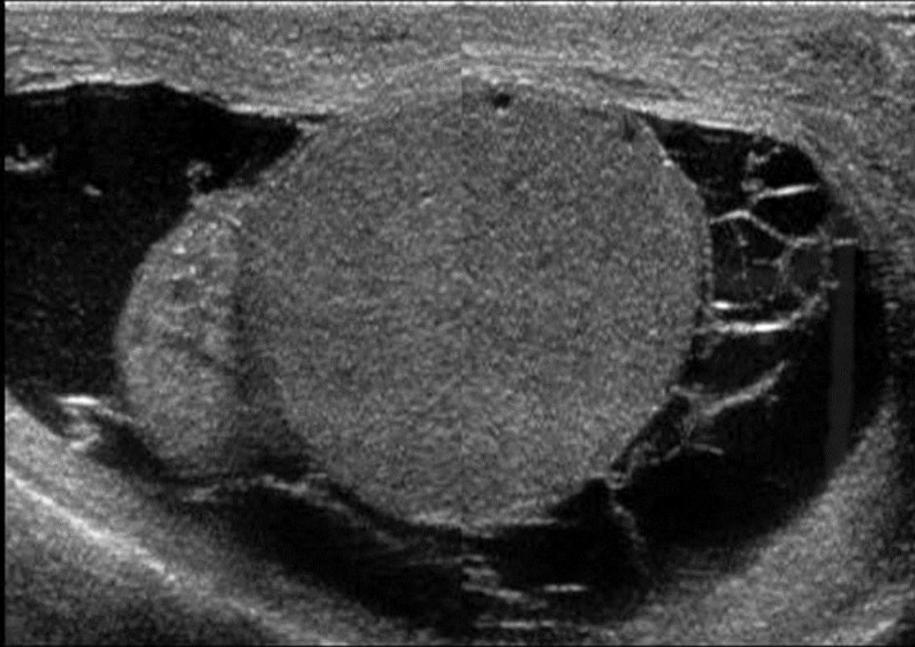


# Linear Sequenced Array

GE MEDICAL SYSTEMS  
IM#10

GE  
+0:00:00

5cm5cm M12L  
CO SCROTAL  
FROZEN  
33G33  
78DR78



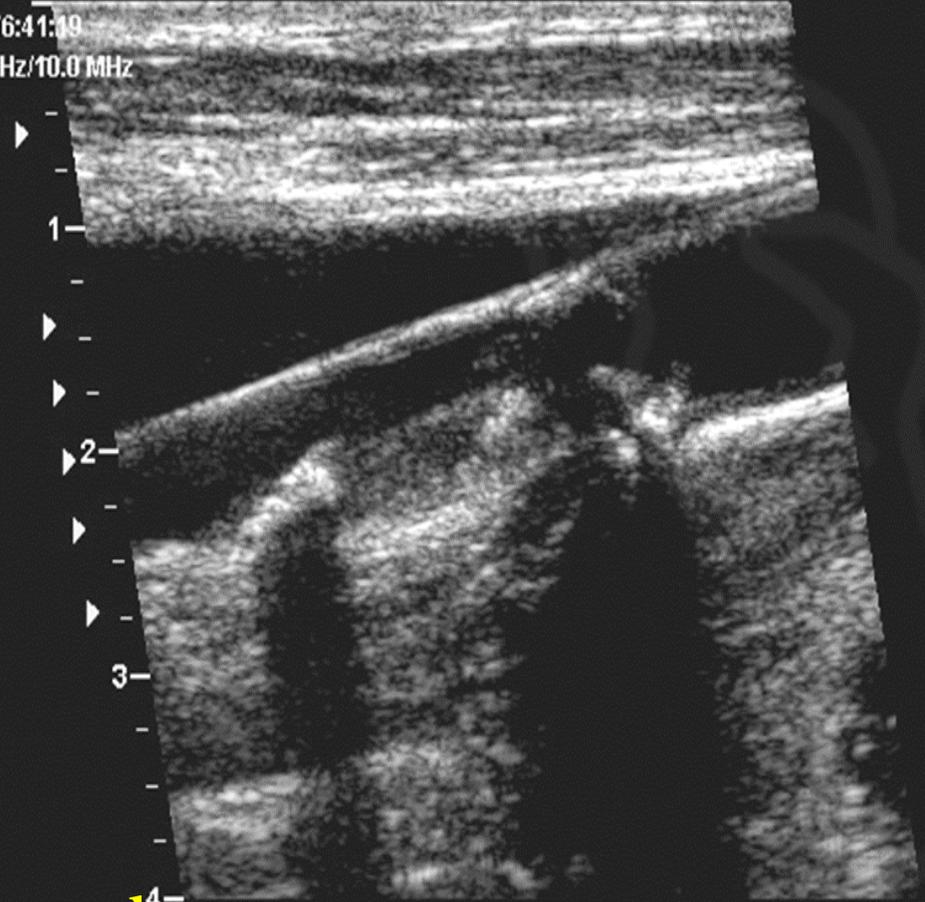
**Unsteered**

ORCHITIS

ESP Ultrasound

copyright © Sidney K. Edelman, Ph. D with permission MI < 0.4 AO=100%

6:41:10  
Freq.: 10.0 MHz/10.0 MHz



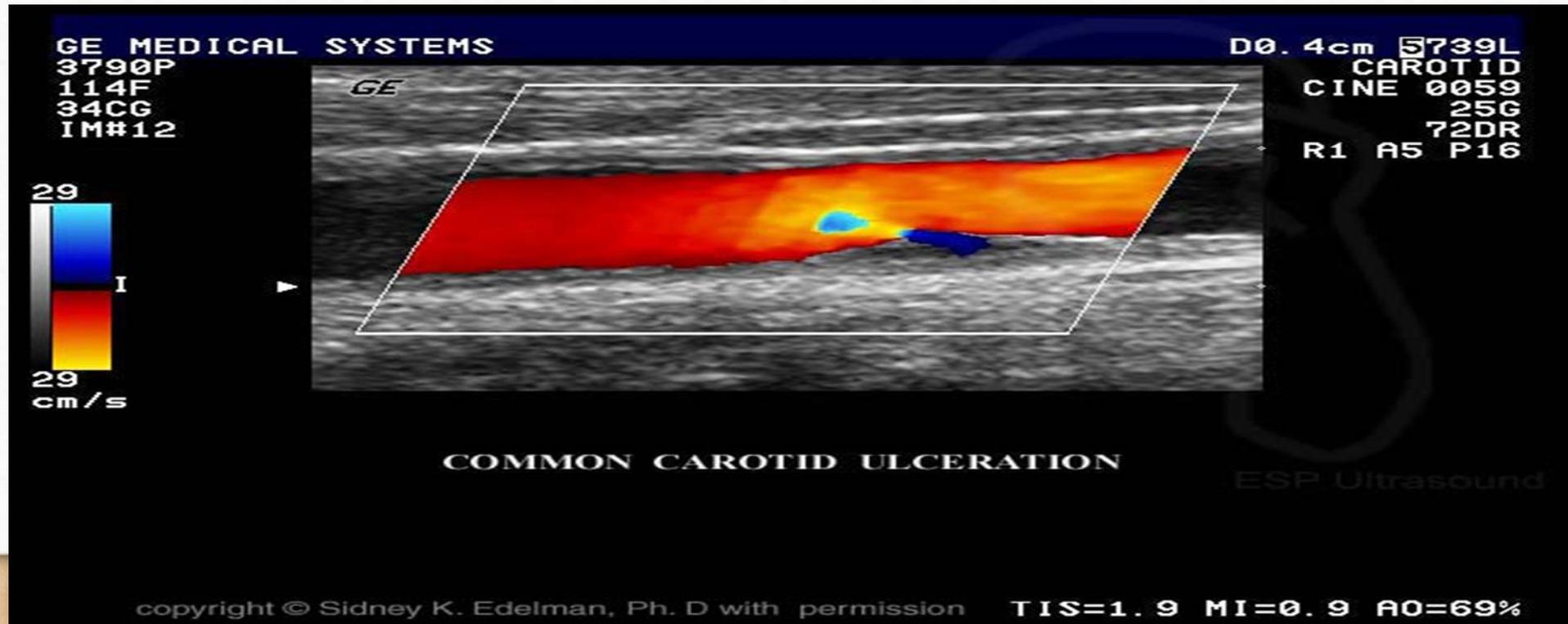
**Steered**

ESP Ultrasound

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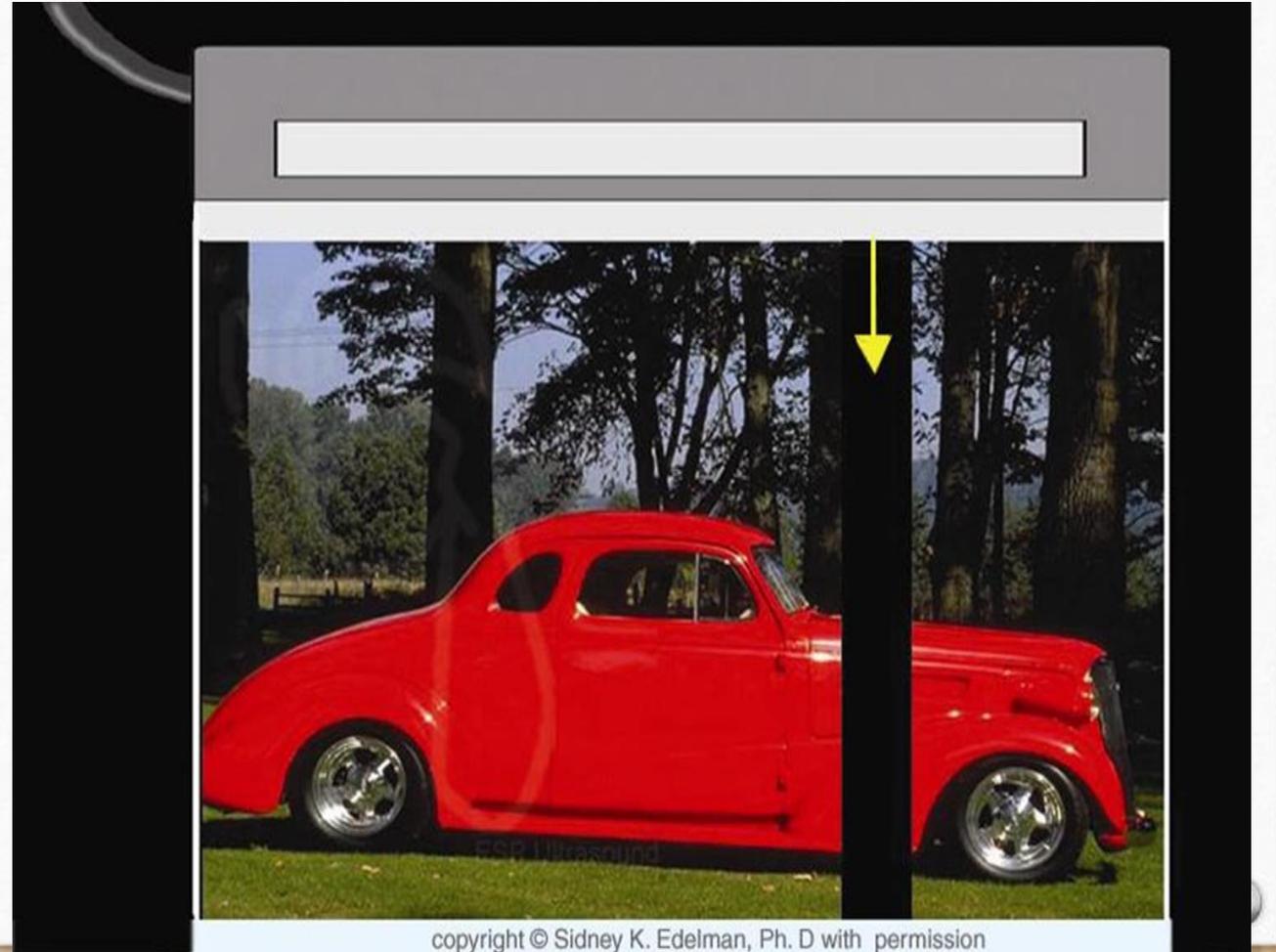
# Linear Sequence Array

- Grayscale – electrical patterns creating beam have no slope
- Color Doppler – electrical spike patterns are sloped



# Linear Sequenced Array

- What happens to your image if a crystal becomes damaged?
  - Only the portion of the image extending directly below the damaged crystal is affected



# Curved Sequenced Array

- Convex
- Curvilinear
- Curved Sequential Array



This our main transducer  
when imaging Abdomen and  
Ob/Gyn – think C5-1!

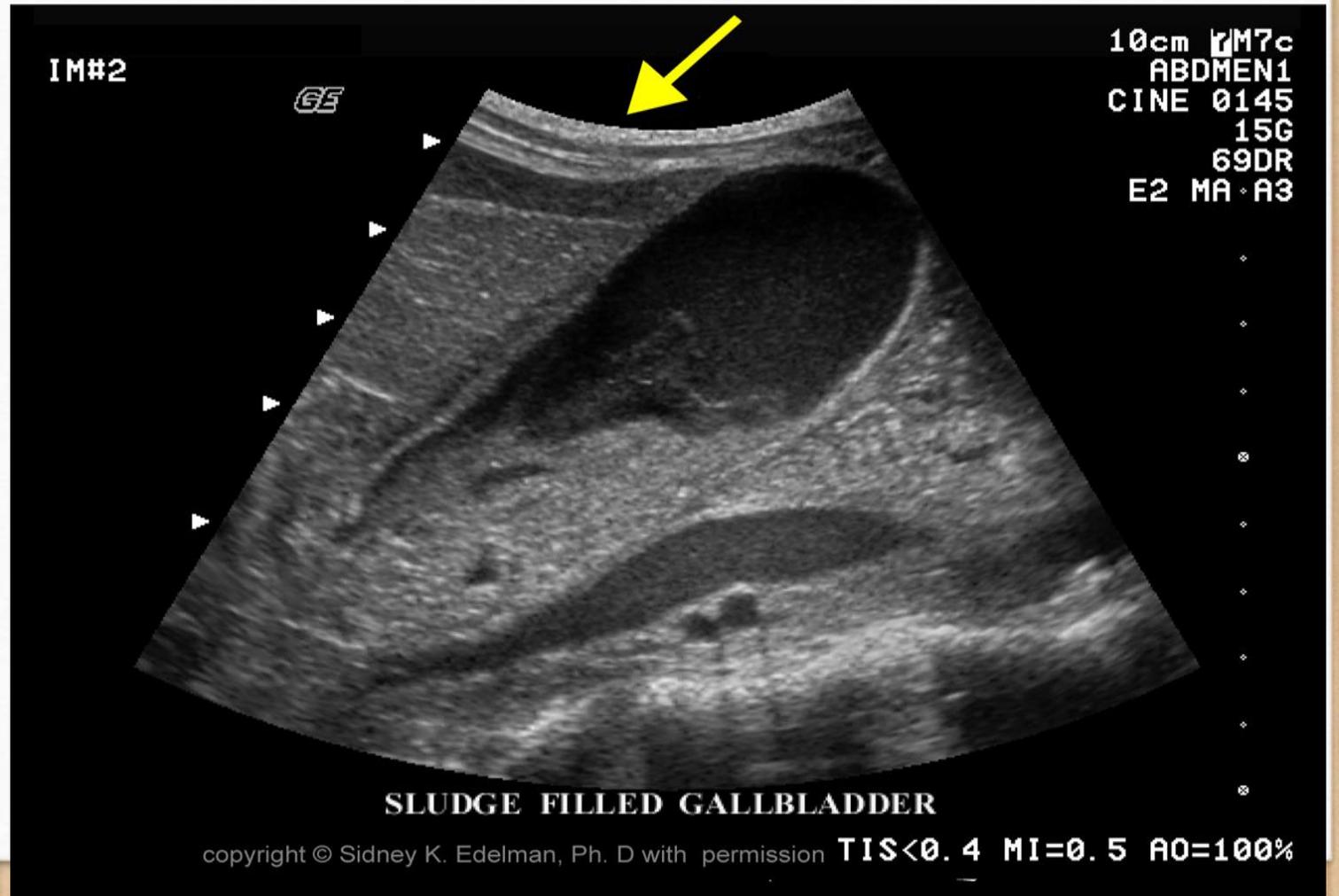
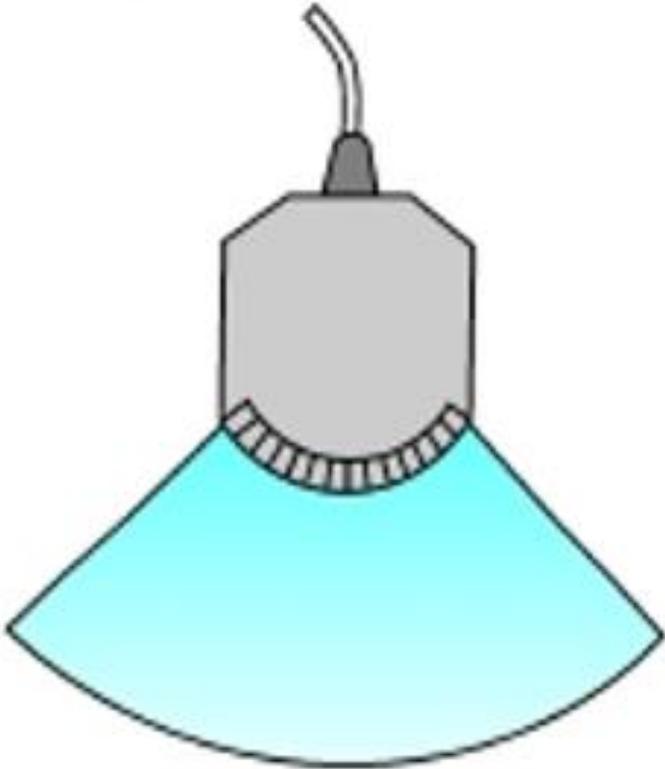
- With curvilinear transducers, all elements are arranged in a line, but only small group of elements are activated in a sequence
- Creates a blunted sector-shaped image

# Curved Sequence Array

- Larger footprint than most other transducers
- Beam steering is achieved by firing small groups of crystals
  - The face of the transducer is curved so it allows pulses to radiate out in an arc-like fashion
- Beam focusing is achieved by sending electrical pulses to groups of crystals with timing delays that creates a curved pattern during transmission
- Dynamic receive focusing delays the signals returning during reception

# Curved Sequence Array

Curvilinear-Array  
Sector Transducer



# Curved Sequence Array



- What happens to your image if a crystal becomes damaged?
  - Only the portion of the image extending directly below the damaged crystal is affected

# Phased Arrays

- Sector
- Vector
- Phased Array



Great for cardiac imaging,  
neonatal heads, some  
endocavitary transducers

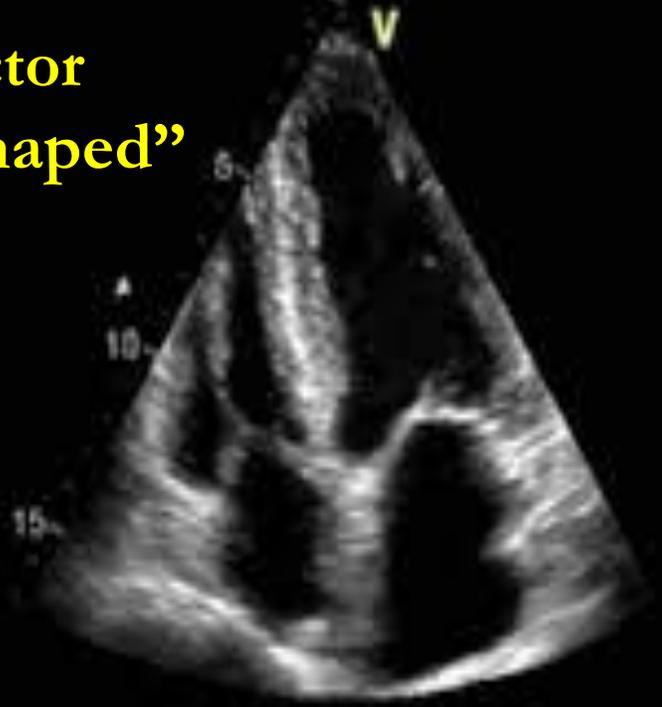
- Unlike the linear and curved transducers, the phased array shape does not resemble the shape of the image
  - Scan lines originate from the same point of origin
- Creates either a “pie-shaped” image or a vector image (flat-top, trapezoidal image shape)

# Phased Arrays

- Much smaller footprint than most other transducers
- Beam steering and focusing is achieved through the electronics of the system
  - Phasing the electrical excitation pattern of the crystal to shape and steer the beam
- Dynamic receive focusing delays the signals returning during reception

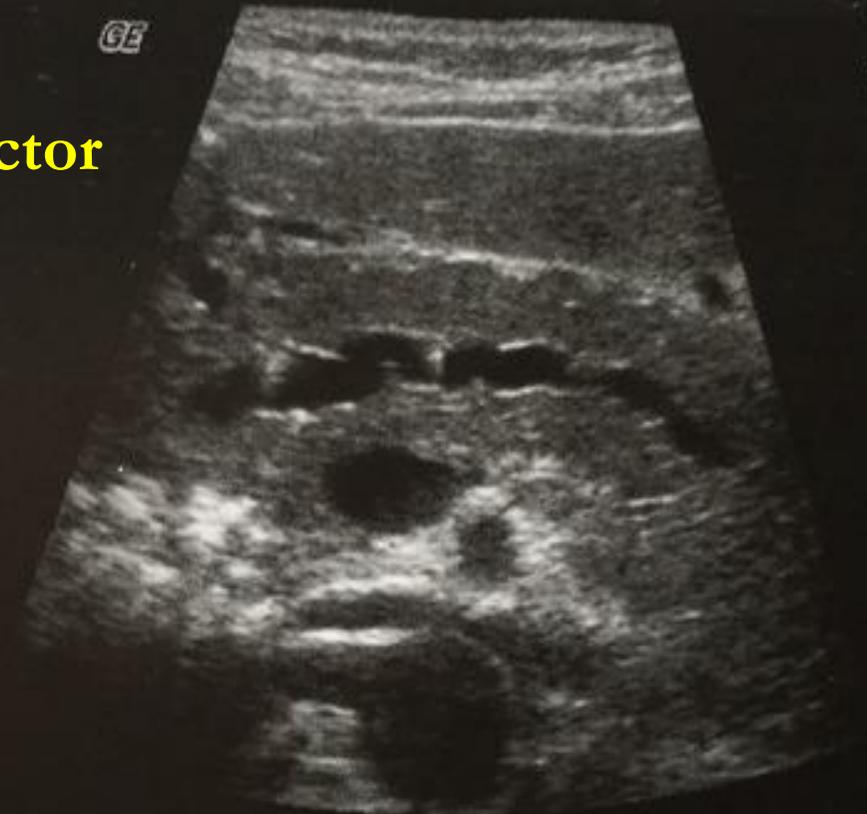
# Phased Arrays

Sector  
"Pie-Shaped"



56  
MakeAGIF.com

Vector



8cm 6546L  
ABDMEN1  
CINE 0281  
42G  
66DR  
E3 MD A3

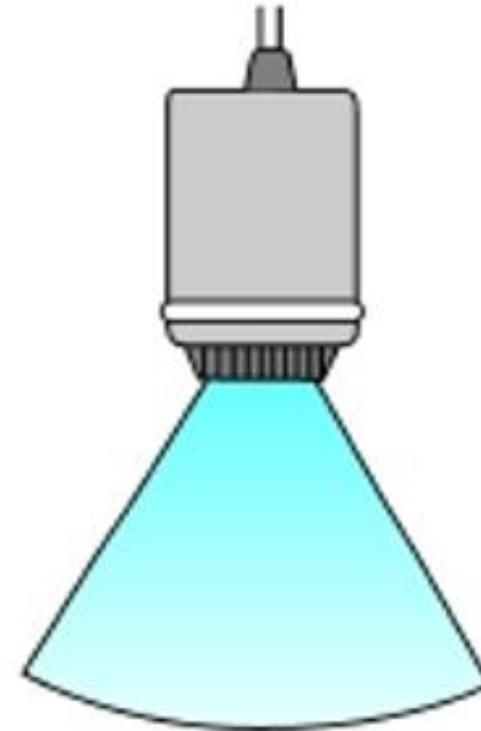
CHRONIC PANCREATITIS

TIS<0.4 MI=0.4 AO=100%

# Phased Arrays

- What happens to your image if a crystal becomes damaged?
  - Results in inconsistent and erratic steering and focus
  - Cannot predict how severely image will be affected because each sound pulse is complex

Phased-Array  
Sector Transducer



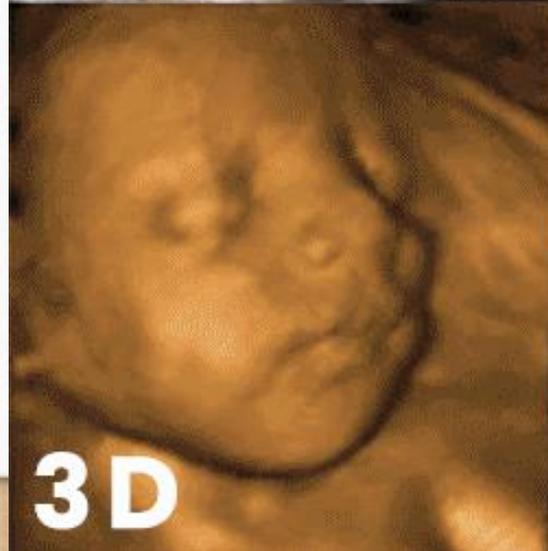
<b>Transducer</b>	<b>Image Shape</b>	<b>Steering Technique</b>	<b>Focusing Technique</b>
<b>Mechanical</b>	<b>Sector</b>	<b>Mechanical</b>	<b>Fixed</b>
<b>Linear Switched</b>	<b>Rectangular</b>	<b>Electronic</b>	<b>Electronic</b>
<b>Linear Phased Array</b>	<b>Sector</b>	<b>Electronic</b>	<b>Electronic</b>
<b>Convex</b>	<b>Blunted Sector</b>	<b>Electronic</b>	<b>Electronic</b>
<b>Vector</b>	<b>Trapezoidal</b>	<b>Electronic</b>	<b>Electronic</b>

# Three-Dimensional Transducers

- Three-dimensional (3D) ultrasound images are traditionally made up of two-dimensional (2D) acquisitions placed next to each other
- There are three different ways to create the 3D image: freehand, with a mechanical transducer, or the newest method, electronically, with the newest 2D array technology

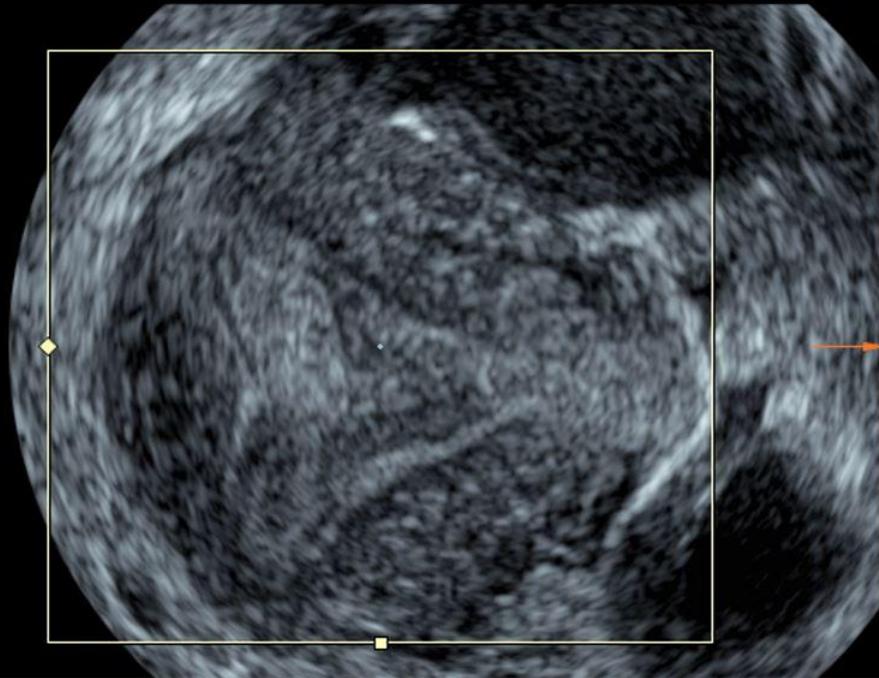
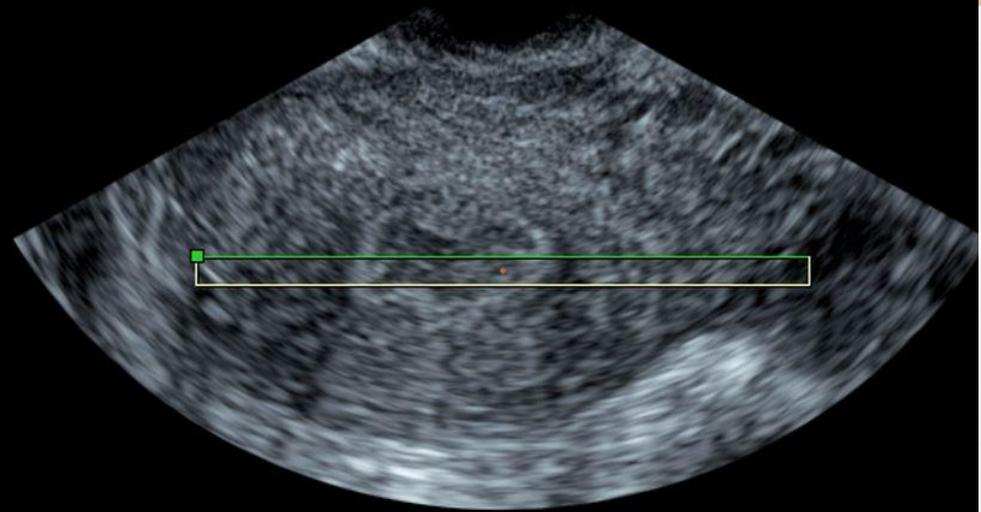


# Three-Dimensional Transducers



# Three-Dimensional Transducers

- Freehand method, aka manual, the sonographer is responsible for moving the transducer through a path to gather the 2D slices
  - Highly operator dependent
  - Requires steady hand moving at the same speed over the tissues
  - Unable to obtain measurements because of variability potential
- The 2D slices, once converted to 3D format, may then be sliced to view coronal, sagittal, and axial planes

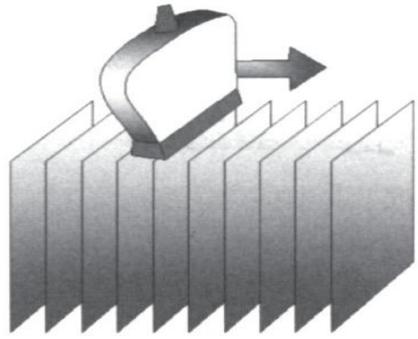


# Three-Dimensional Transducers

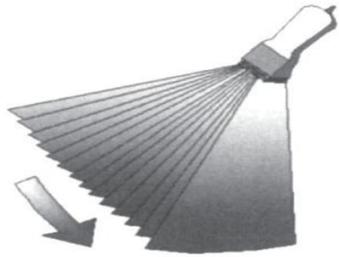
- Mechanical technique, aka automated or mechanical 3D method, specialized transducers have been developed that are essentially curved sequenced array transducers mounted onto a motor
- These transducers permit measurement on the screen of the 3D image as well as the use of real-time 3D, also known as four-dimensional (4D) ultrasound

# Three-Dimensional Transducers

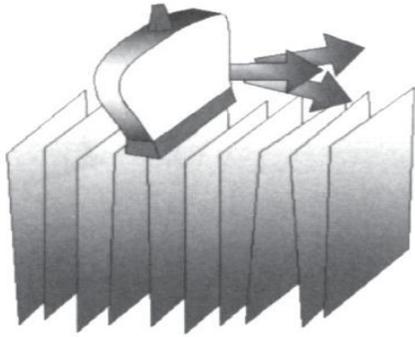
- The **frame rate** of the 4D image is limited by the speed of the motor to which the transducer is attached
- The latest technology for acquiring a 3D image is the new electronic array, called a 2D transducer or matrix array transducer
- These transducers acquire real-time volumes using transducers with up to 10,000 elements compared to the 128 to 512 elements used in standard 1D array transducers



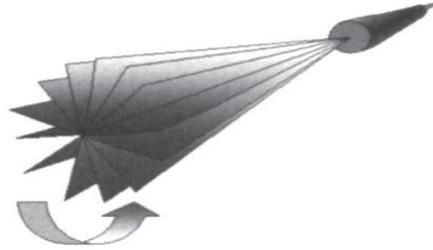
Linear



Wedge

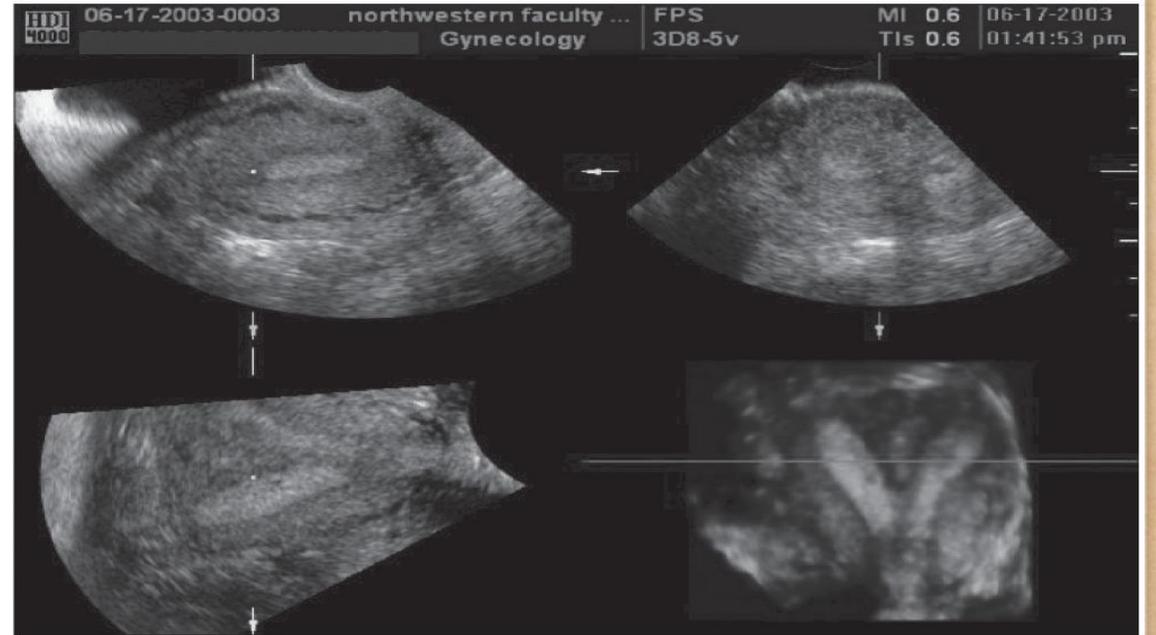


Freeform



Rotational

A



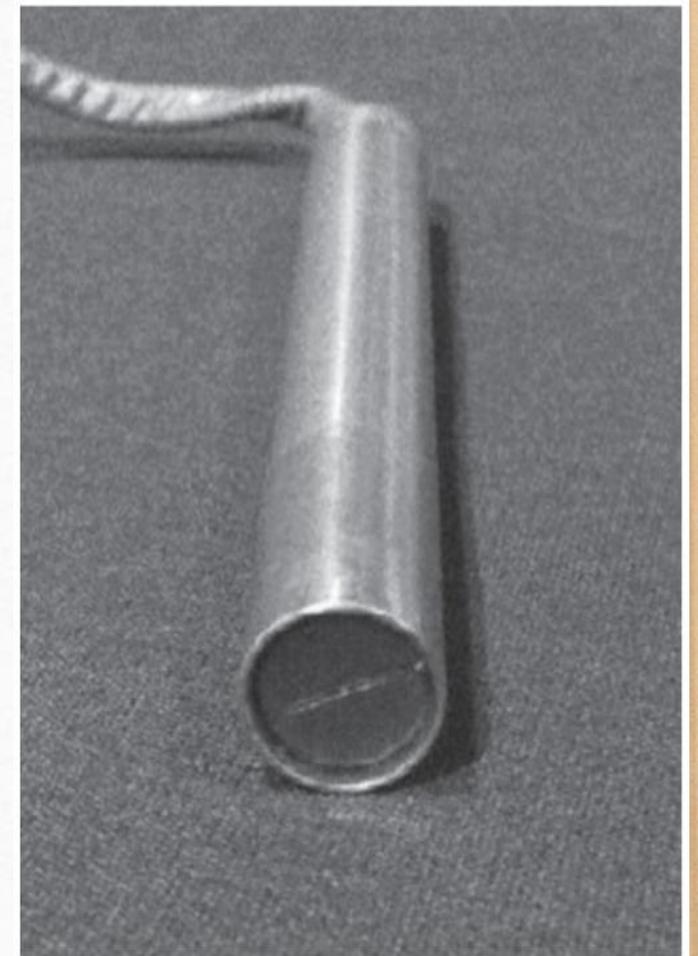
B



C

# Continuous Wave (CW) Transducers

- Most often used in Doppler studies
- Contains 2 piezoelectric elements:
  1. One continuously transmits sound
  2. One continuously receives sound
- Cannot produce an image with a CW transducer
- Do not have range resolution



# Resolution

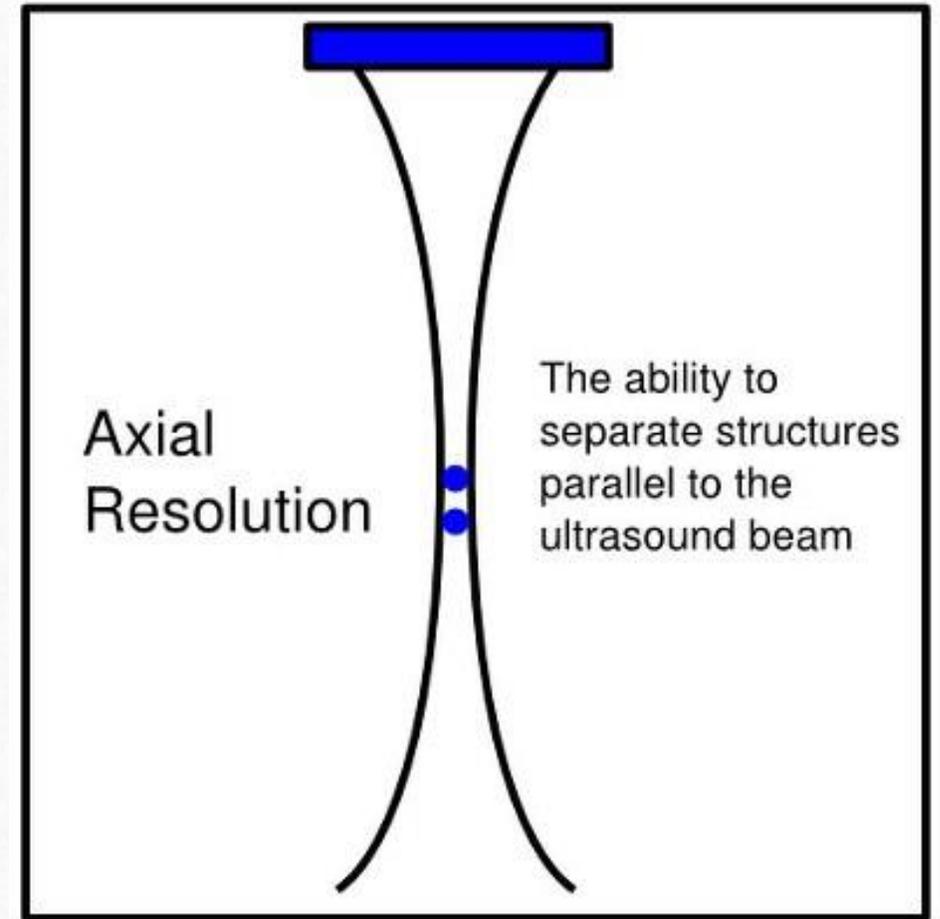
- Resolution is the ability to create *accurate* images
- Many ways to describe image accuracy and thus, many different types of resolution:
  1. Spatial
    - a. Axial
    - b. Lateral
    - c. Elevational
    - d. Contrast
  2. Temporal

# Spatial Resolution

- Defined as the ability of the system to distinguish between closely spaced objects
- Relates to the quality of the detail of the image
- Divided into four components:
  1. Axial Resolution
  2. Lateral Resolution
  3. Elevational Resolution
  4. Contrast Resolution

# Axial Resolution

- Ability of a system to display two structures that are very close together
  - Structures are parallel to the main beam axis
- Minimum distance two reflectors can be, parallel to the beam, and still appear on the screen as two dots



# Axial Resolution

- **Units:** any unit of distance (cm, mm)
- Typical values: 0.1 – 1.0 mm
  - **Lower number is best!**
    - Shorter pulses
    - Improved image accuracy
- Determined by:
  - Spatial Pulse Length
  - Pulse Duration
- Not adjustable by the sonographer

# Axial Resolution

- Good axial resolution means we have short pulses
- Short pulses means:
  - Short spatial pulse length *or*
  - Short pulse duration
- Transducers are designed with backing material to have fewer cycles per pulse
  - Backing material keeps the numerical axial resolution low and image accuracy is superior

# Axial Resolution

- In order to improve axial resolution, you would need a new transducer
- Also known as **“LARRD”**
  - **Longitudinal**
  - **Axial**
  - **Range**
  - **Radial**
  - **Depth**

# Axial Resolution

$$\text{Axial resolution (mm)} = \frac{\text{SPL (mm)}}{2}$$

$$\text{Axial resolution} = \frac{\text{wavelength} \times \# \text{ cycles in pulse}}{2}$$

- Transducers that have better axial resolution have shorter pulses created by:
  - Less ringing (fewer cycles) due to increased damping material
  - Higher frequencies (shorter wavelengths)

# Axial Resolution

- If numerical question on boards
  - Axial resolution is best in transducers with
    - Highest frequency
    - Fewest # of cycles/pulse
  - Axial resolution is worst in transducers with
    - Lowest frequency
    - Largest # of cycles/pulse

# Axial Resolution

- Options that give you superior axial resolution:
  1. Shorter Spatial Pulse Length
  2. Shorter Pulse Duration
  3. Higher Frequencies (shorter wavelengths)
  4. Fewer Cycles Per Pulse (less ringing)
  5. Lower Numerical Values

# QUESTIONS

---

Which of the following transducers has the poorest axial resolution?

- A.** 1.7 MHz and 4 cycles/pulse
- B.** 2.6 MHz and 3 cycles/pulse
- C.** 1.7 MHz and 5 cycles/pulse
- D.** 2.6 MHz and 2 cycles/pulse

\_\_\_\_\_ frequency transducers generally have the best range resolution.

**A. Low**

**B. High**

The more cycles in a pulse, the \_\_\_\_\_  
the numerical value of the range  
resolution.

**A. Greater**

**B. Lesser**

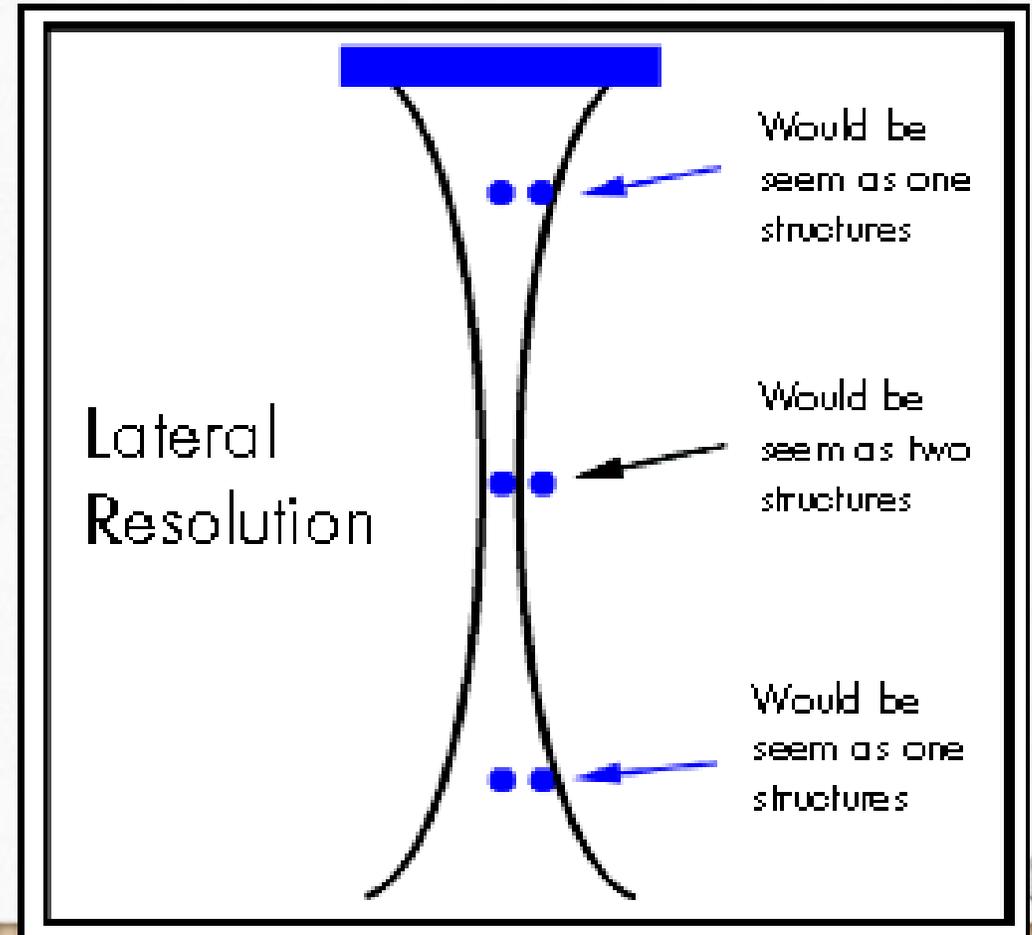
**C. Same**

Which of the following transducers has the best axial resolution?

- A.** 1.7 MHz and 4 cycles/pulse
- B.** 2.6 MHz and 3 cycles/pulse
- C.** 1.7 MHz and 5 cycles/pulse
- D.** 2.6 MHz and 2 cycles/pulse

# Lateral Resolution

- Lateral resolution relates to the width of the beam and the reflectors that lie perpendicular to it
  - Identifies structures that are side-to-side or perpendicular to the sound beam



# Lateral Resolution

- Lateral resolution is equal to the beam diameter
  - Since beam diameter varies with depth, lateral resolution also varies with depth
- **Units:** any unit of distance (cm, mm)
- Typical values: 0.1 – 1.0 mm
  - **Lower number is best!**
- Determined by:
  - Width of the sound beam (narrow is better)

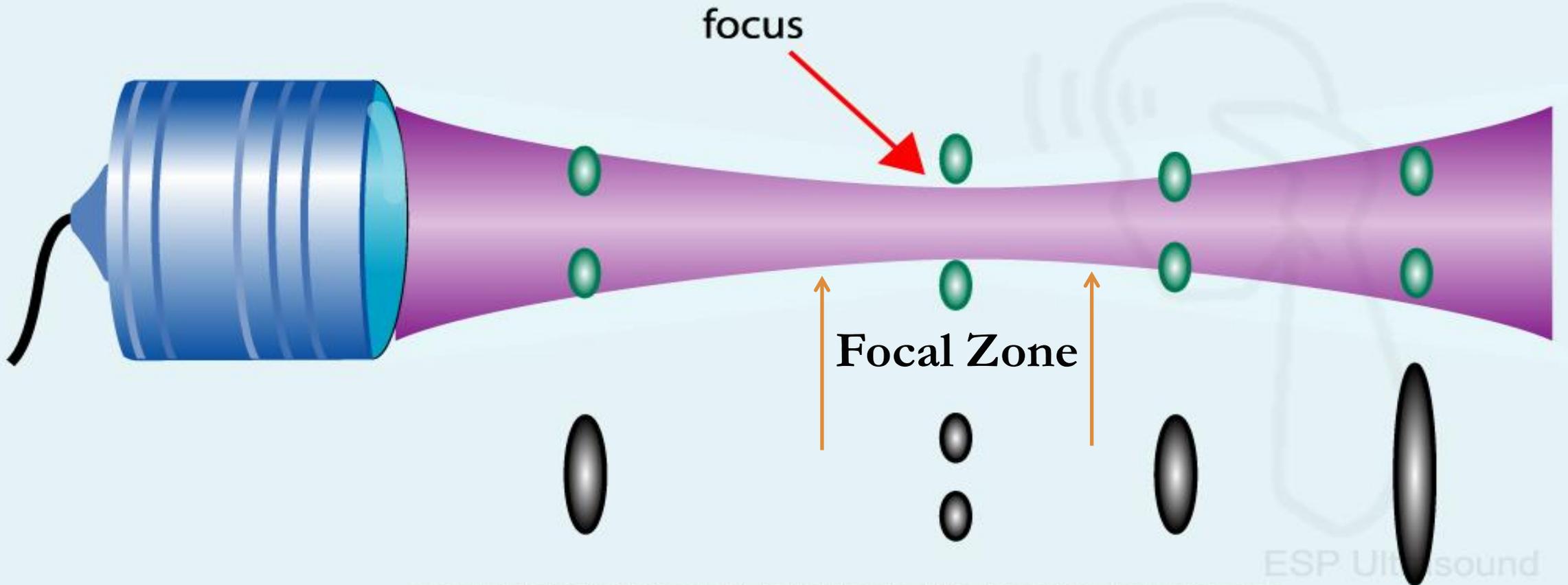
# Lateral Resolution

- Also known as **“LATA”**
  - **Lateral**
  - **Angular**
  - **Transverse**
  - **Azimuthal**

# Lateral Resolution

- Because lateral resolution is dependent on sound beam width, it is ever changing as the sound beam travels into tissue
  - Best lateral resolution is found at the focus (narrowest section of the sound beam)
  - Good lateral resolution is found within the focal zone

# Lateral Resolution



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ESP Ultrasound

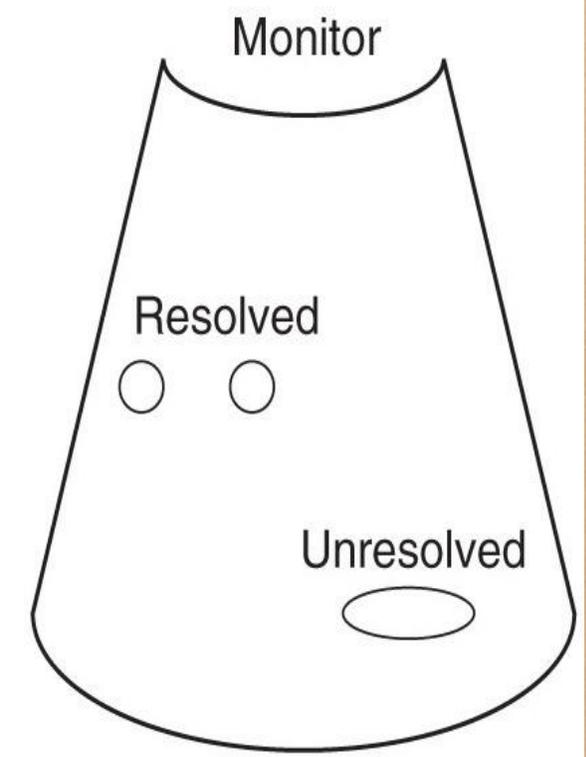
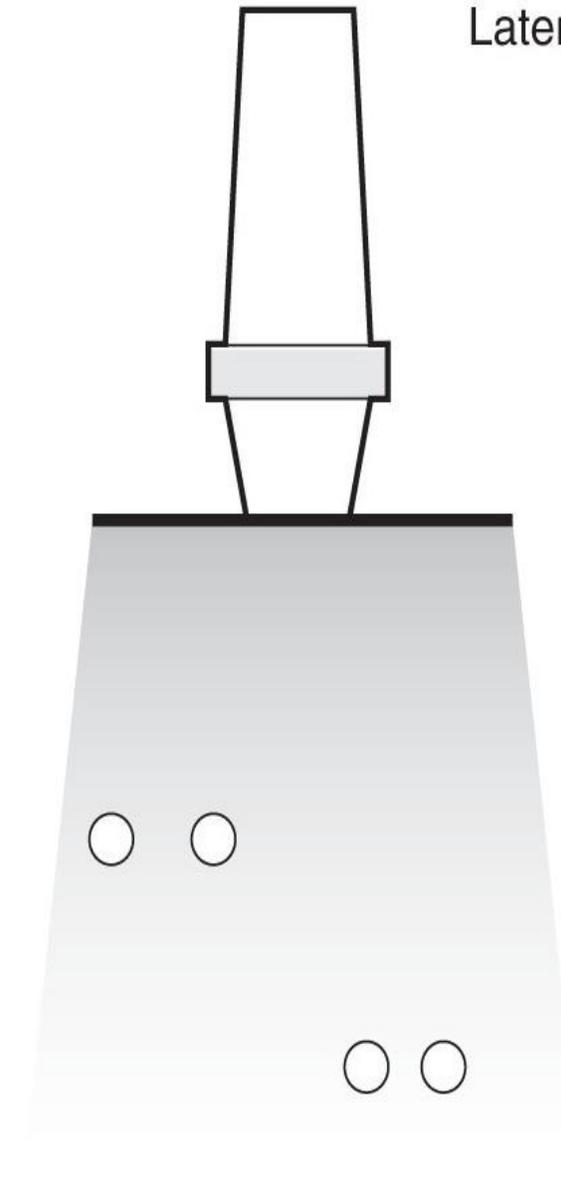
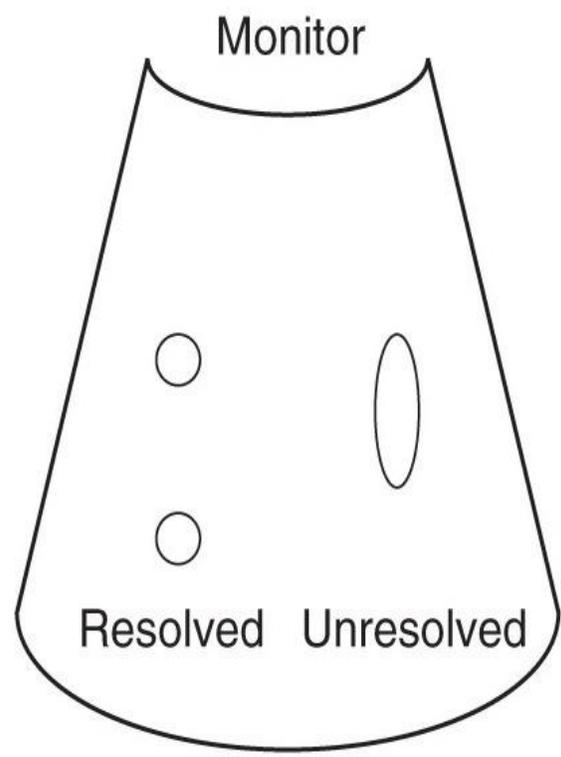
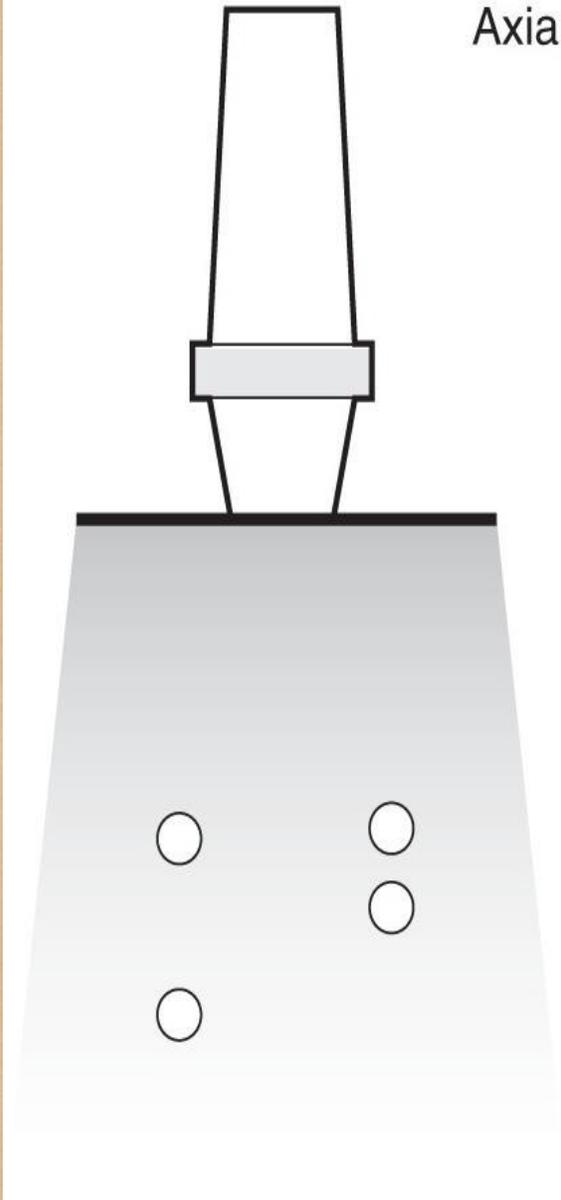
# Axial/Lateral Resolution

- If you had to choose, which would be more important?
  - Axial resolution
    - Keep the pulses shorter for better diagnostic quality images
- What are the advantages of using a high frequency transducer?
  - Axial resolution – shorter pulses associated with higher frequencies
  - Lateral resolution – higher frequency pulses diverge less (stay narrower)

	AXIAL	LATERAL
<b>Orientation</b>	Front-to-back parallel to beam	Side-by-side perpendicular to beam
<b>Mnemonic</b>	LARRD	LATA
<b>Determined by</b>	Pulse length	Beam width
<b>Best with:</b>	shortest pulse highest frequency & fewest cycles	narrowest beam
<b>Changes</b>	same at all depths, does not change	changes with depth, best at focus
<b>In Near Field, best with</b>	shortest pulse	smallest diameter crystal
<b>In Far Field, best with</b>	shortest pulse	largest diameter & highest frequency (least divergence)

Axial resolution

Lateral resolution



**A**

**B**

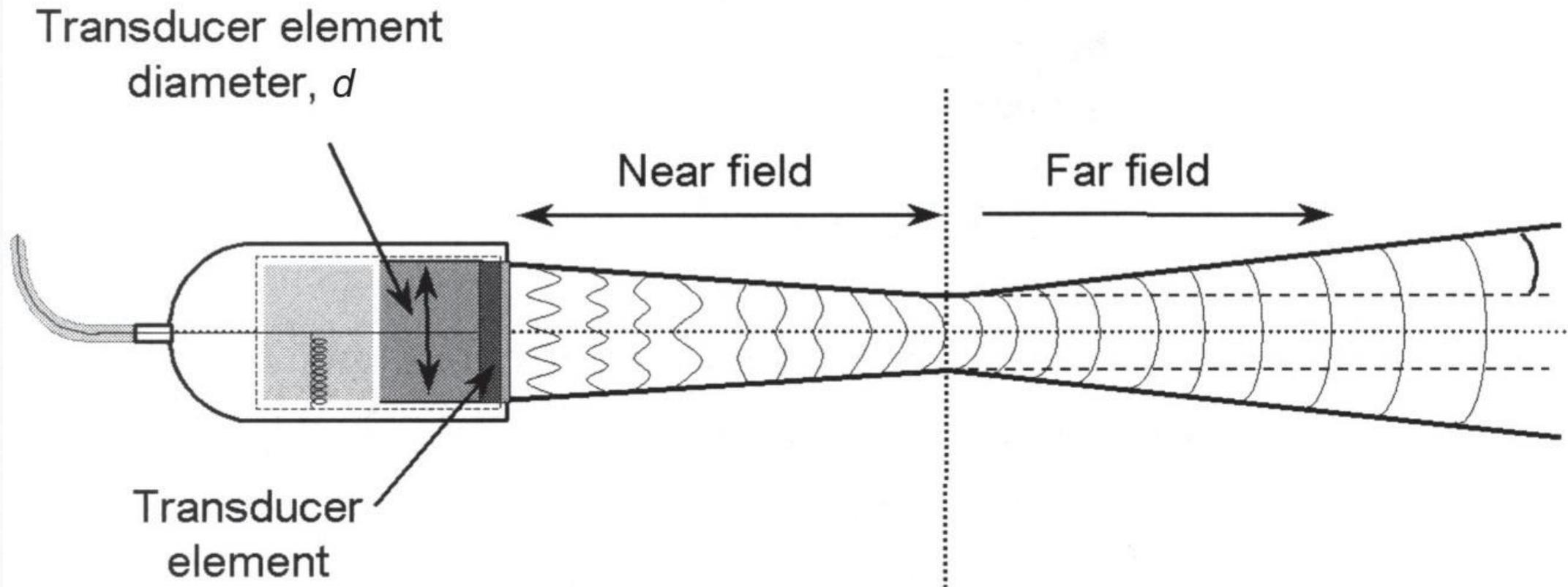
# Sound Beam Shape

- The diameter of the beam is determined by both the frequency and the diameter of the element itself, also referred to as the **aperture**
- The beam takes on a shape in the appearance of an hourglass
- As the beam leaves the transducer and travels into the patient, the diameter of the beam varies with distance
- The beam begins to narrow immediately upon leaving the transducer
- At its narrowest point, it is called the **focal point**

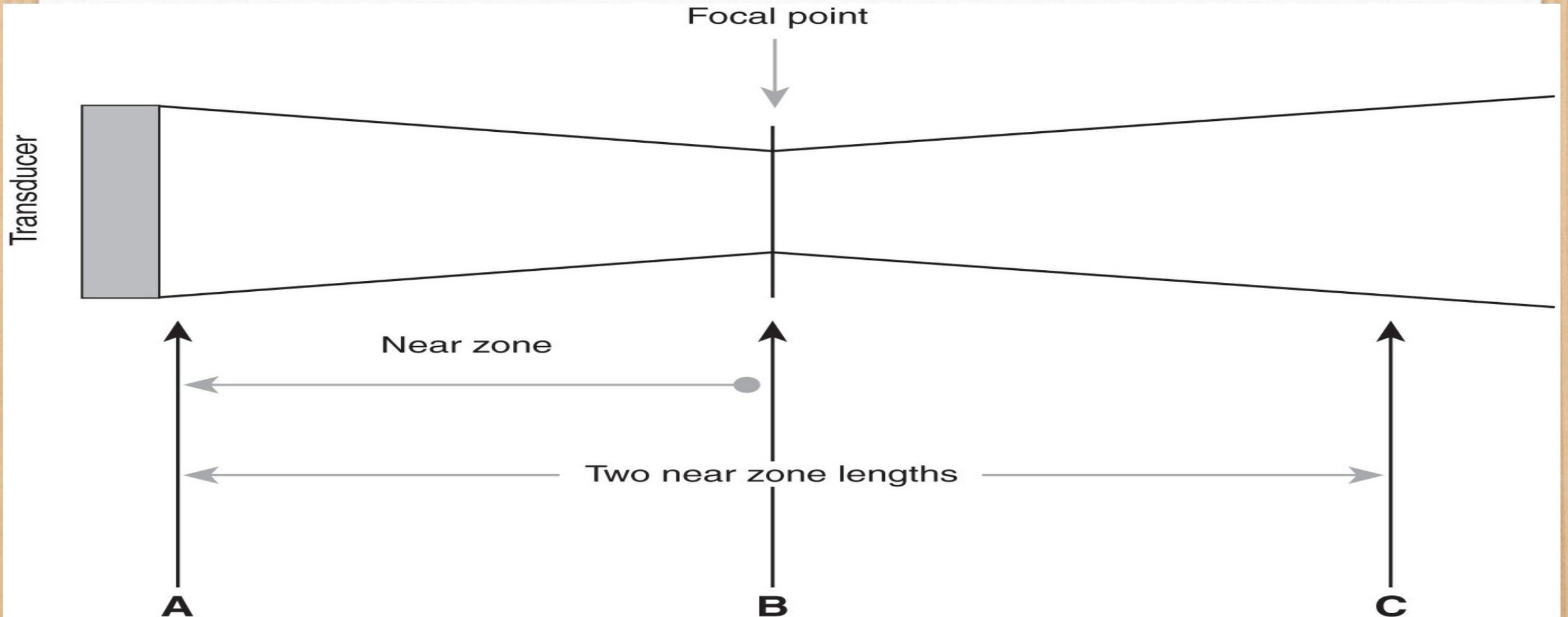
# Sound Beam Shape

- The region from the transducer face to the focal point is called the **near zone** or **Fresnel zone**
- Subsequently, the length of the near zone is referred to as the **near zone length** (NZL)
- After the focal point is reached, the beam starts to diverge, or spread
  - The region distal to the focal point is called the **far zone** or **Fraunhofer zone**

# Sound Beam Shape



# Sound Beam Shape



# Sound Beam Shape

- **Divergence** of the beam, or the spreading out of the beam, is detrimental to lateral resolution
  - A narrow beam width is desired in order to have good lateral resolution
- Subsequently, the focal zone should be placed at or below the area of interest to obtain the best lateral resolution in that area
- Both the actual diameter of the element and the frequency of the transducer determine the NZL and the amount of divergence in the far field

# Sound Beam Shape

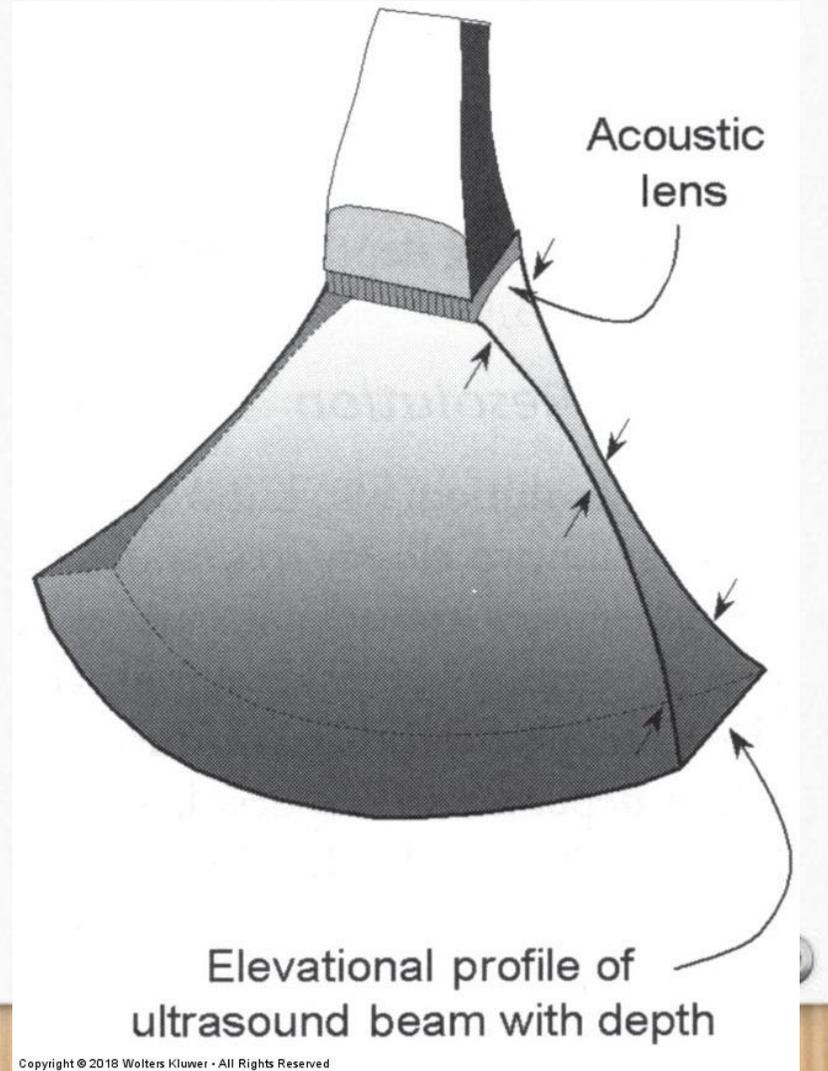
- A smaller aperture (diameter of the element) results in a shorter NZL and more divergence in the far field
  - If the transducer and the frequency do not change, but a larger aperture is utilized, a longer NZL will result, with less divergence in the far field
- The same theory is true for identical aperture size, but different frequencies
  - The lower the frequency, the shorter the NZL, with an increase of divergence in the far field

# Sound Beam Shape

- Conversely, the higher the frequency, the longer the NZL, with less divergence in the far field
- As with axial resolution, the smaller the numerical value for lateral resolution, the better
  - For example, a lateral resolution of 0.2 mm is better than a lateral resolution of 0.4 mm
- Most transducers have better axial resolution than lateral resolution

# Elevational Resolution

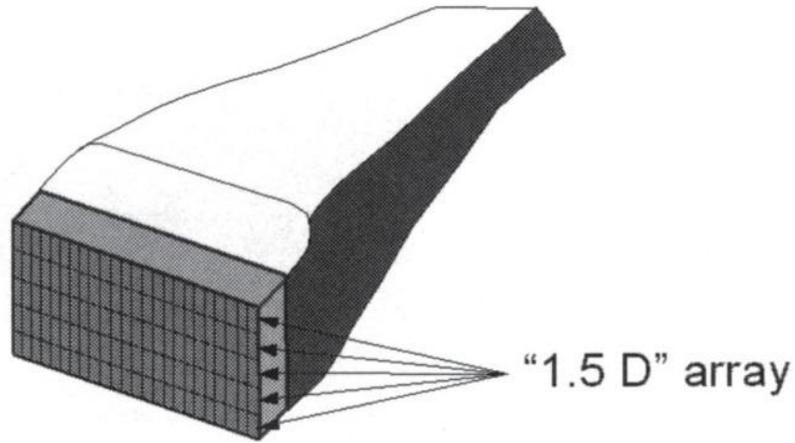
- Elevational resolution is determined by the thickness of the imaging plane
- The image on the monitor is a compressed version of any object located within the ultrasound beam
  - Can create artifact or false echoes within a cystic structure because the beam is also slicing through the tissue next to the cyst



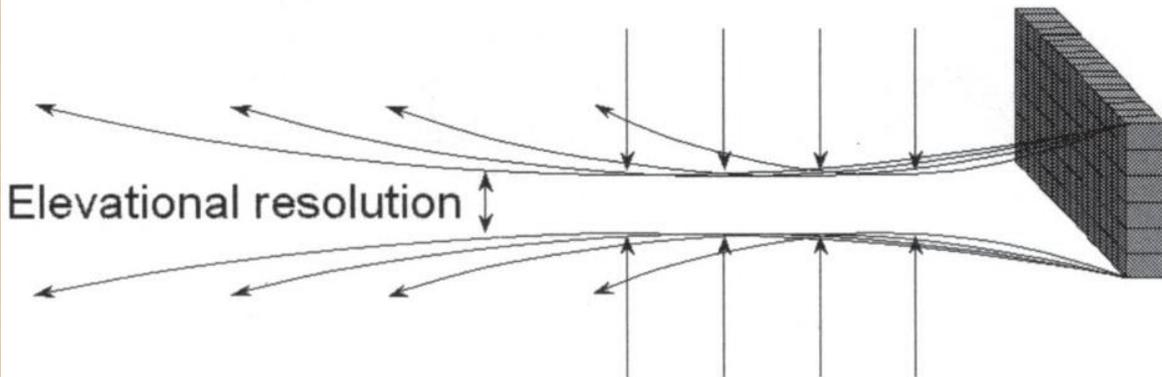
# Elevational Resolution

- This third dimension of the beam is called the **slice-thickness plane**
  - AKA **section-thickness plane** or the **elevation plane**
- Thinnest elevation plane is optimal for diagnostic imaging
  - Focusing helps to achieve thin elevational planes
  - Most transducers employ a lens, or fixed focusing method, to achieve a thin elevation plane
    - Focus is fixed and does not change regardless of depth

# Elevational Resolution



Multiple transmit focal zones: elevational plane



- Newest technology can adjust the elevational plane electronically
- 1 1/2 dimensional array transducers
  - Automatically change the slice-thickness focal zone when the focus is changed by the sonographer

# Contrast Resolution

- **Contrast resolution** is the ability to distinguish between different shades of gray
- Adjusting the systems dynamic range will compress signals to create several available gray shades that are visible to the eye
  - Discussed more in Chapter 3

# Temporal Resolution

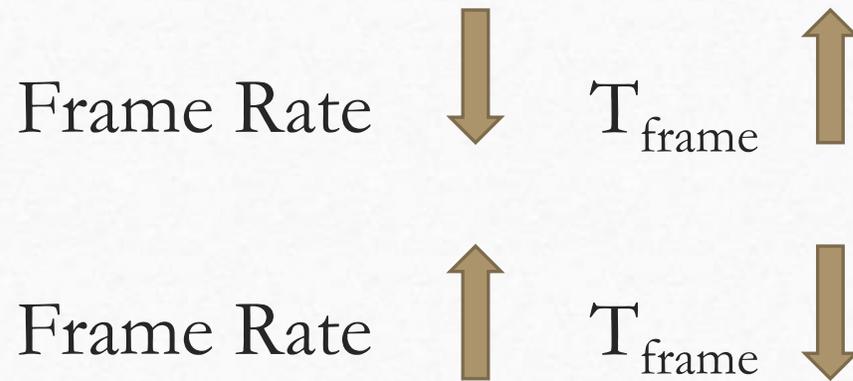
- **Temporal resolution** represents time, or the ability to display structures in real time
  - Related to how quickly frames are generated
  - Excellent when system produces many frames per second
- Another, more commonly used term for temporal resolution is **frame rate**
- A complete ultrasound image, or frame, needs to be placed on the screen, scan line by scan line, before the next frame can begin to be placed

# Temporal Resolution

- The longer it takes a frame to be displayed on the screen, the lower the frame rate, and the worse the temporal resolution
- “High Frame Rate”
  - High number of images created per second, improved temporal resolution
- “Low Frame Rate”
  - Few images created per second, degraded temporal resolution
- **Units:** Hertz (Hz) or frames/second

# Temporal Resolution

- Frame rate and time to produce one frame ( $T_{\text{frame}}$ ) are inversely related



- Also, reciprocals!
  - $T_{\text{frame}} \times \text{frame rate} = 1$

# Temporal Resolution

- If the system creates an image in  $1/10$  sec ( $T_{\text{frame}}$ )
  - Frame rate is 10 Hz or 10 frames per second
- Most ultrasound machines have frame rates between 20-100 Hz!

# Temporal Resolution

- There are three adjustments that can be made to alter the frame rate in grayscale imaging:
  1. Image depth (PRF)
  2. The number of focal zones
  3. The number of scan lines per frame
    - a) Sector size
    - b) Line density

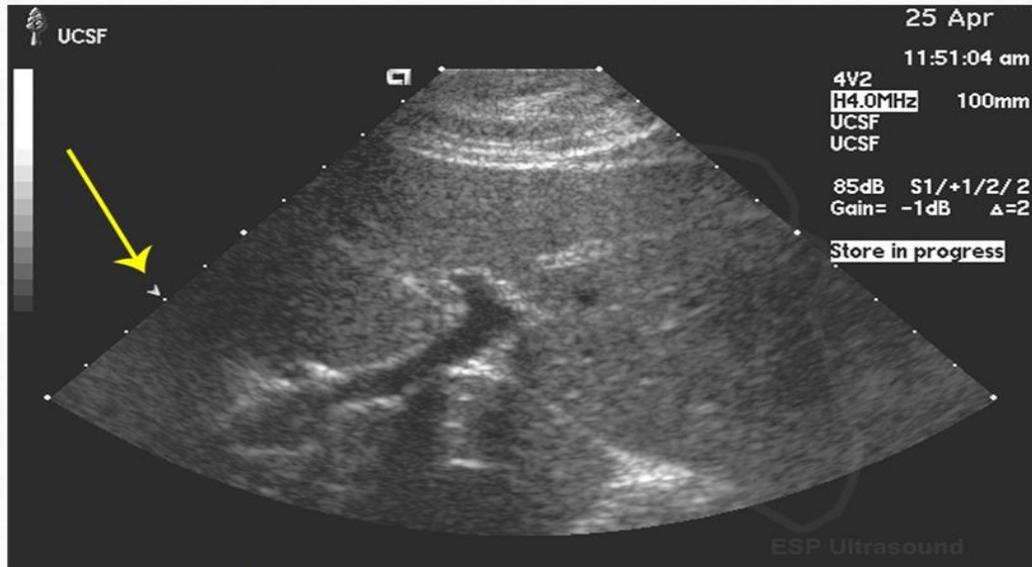
# Temporal Resolution & Image Depth

- As the depth is increased, the pulse must travel farther or deeper into the body
- A new pulse cannot be sent out until the previous pulse is received
  - The machine must wait before sending out the next pulse
- The longer it takes to create one scan line, the longer it takes to display one frame
  - Therefore, PRF is directly related to frame rate
- The higher the PRF (the shallower the image), the higher the frame rate

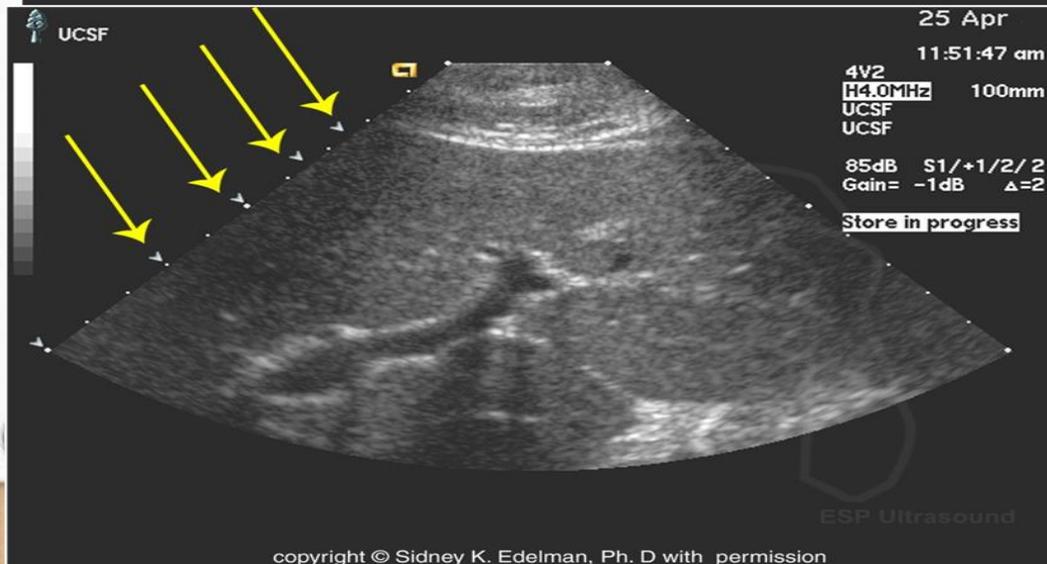
# Temporal Resolution & Focal Zone #

- With One focal zone (only 1 pulse per scan line)
  - Only one sound pulse is transmitted down each scan line (better temporal resolution)
- With Multiple focal zones
  - # of pulses transmitted down each scan line increases
    - # of pulses required increases
  - Decreases frame rate & temporal resolution

# Temporal Resolution & Focal Zone #



- Single focus – only one pulse transmitted down each scan line



- Multi-focus – many pulses transmitted down each scan line

# Temporal Resolution & Focal Zone #

Single Focus	Multi-Focus
One pulse per scan line	Many pulses per scan line
Shorter $T_{\text{frame}}$	Longer $T_{\text{frame}}$
Higher Frame Rate	Lower Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution
Inferior Lateral Resolution	Superior Lateral Resolution

# Temporal Resolution & Focal Zone #

- Advantages of multi-focusing:
  - Improves accuracy of individual images
  - Each scan line has superior lateral resolution (narrower over a wide range of depth)
- Trade off: temporal vs. lateral resolution

# Temporal Resolution & Sector Size

- “Field of View”
- Newer technologies allow the width of the image to be increased or decreased
  - Wider images will require more scan lines compared to a narrower image
- More scan lines that need to be displayed, the longer it takes to create one frame and therefore, the temporal resolution degrades

# Temporal Resolution & Sector Size



- Narrower images results in higher frame rate (fewer scan lines are being used)



- Wider images results in lower frame rate (more scan lines are being used)

# Temporal Resolution & Sector Size

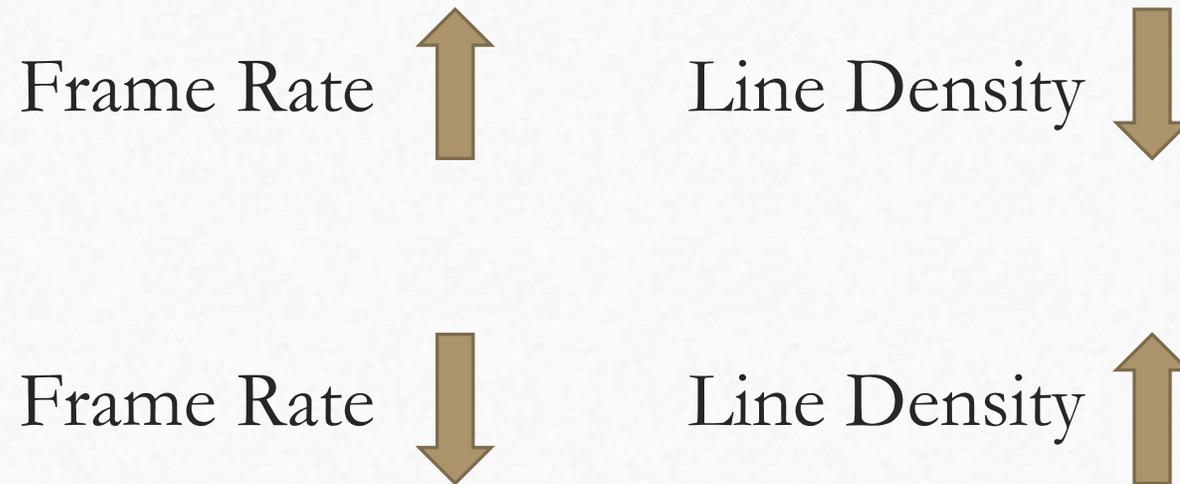
- In the instance where the temporal resolution is inadequate, such as imaging a deep structure while using multiple focal zones, the frame rate can be improved by using a narrower image width, thereby decreasing the number of lines per frame
- Creating an image with a  $30^\circ$  sector requires a certain number of ultrasound pulses. Whereas, a  $90^\circ$  sector image uses three times more pulses

# Temporal Resolution & Sector Size

Narrow Sector	Wide Sector
Fewer pulses per frame	More pulses per frame
Shorter $T_{\text{frame}}$	Longer $T_{\text{frame}}$
Higher Frame Rate	Lower Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution

# Temporal Resolution & Line Density

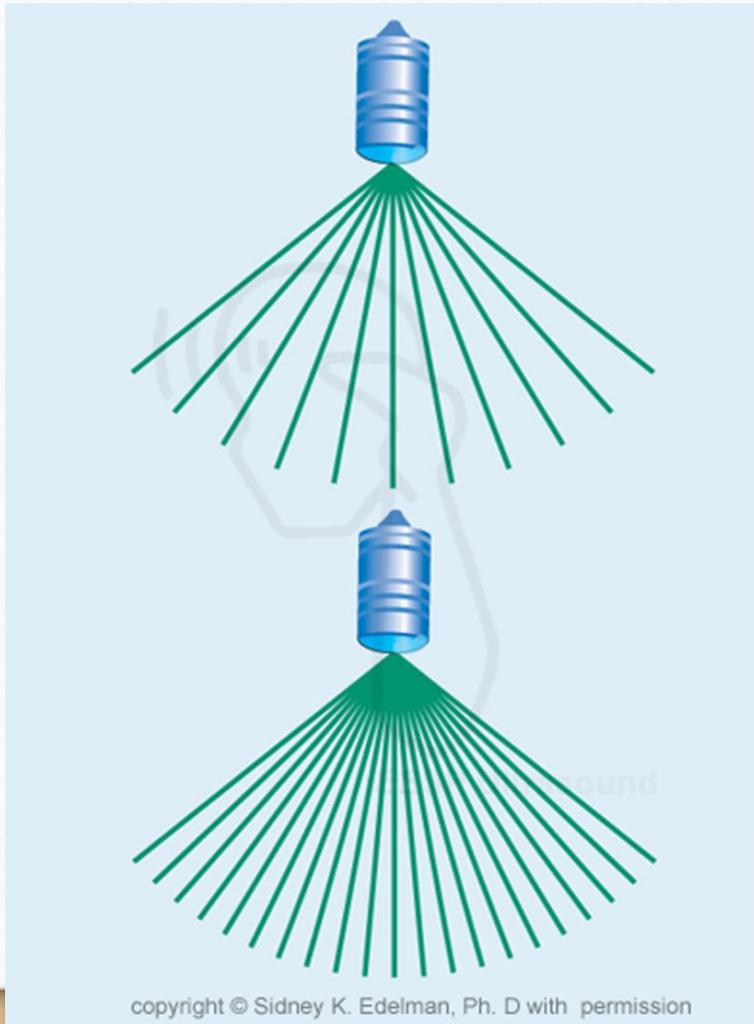
- Some ultrasound systems can alter spacing between scan lines
- Inversely related to frame rate:



# Temporal Resolution & Line Density

- Low line density
  - Lines spaced far apart
    - # of pulses per image decreases
    - Temporal resolution increases
    - Degrades spatial resolution – (detail resolution)
- High line density
  - Lines spaced closely
    - # of pulses per image increases
    - Temporal resolution decreases

# Temporal Resolution & Line Density



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- Images with fewer lines results in higher frame rates
  - Low Line Density
- Images with more lines results in lower frame rates
  - High Line Density

# Temporal Resolution & Line Density

- High Line Density
  - Main advantage: improve spatial resolution
    - More DETAIL!
  - Disadvantage: decreased temporal resolution
    - Lower frame rate

# Temporal Resolution & Line Density

Low Line Density	High Line Density
Widely Spaced Lines	Tightly Packed Lines
Fewer Pulses Per Frame	More Pulses Per Frame
Short $T_{\text{frame}}$	Longer $T_{\text{frame}}$
Higher Frame Rate	Lower Frame Rate
Superior Temporal Resolution	Inferior Temporal Resolution
Inferior Spatial Resolution	Superior Spatial Resolution

# Temporal Resolution/Image Quality

- Trade off between:
  - Excellent image quality
    - Superior “photograph”
  - Excellent temporal resolution
    - Superior “movie”
- Right choice depends on specific setting

# Temporal Resolution/Image Quality

- To produce exceptional image use:
  - Multiple focusing
  - Wide field of view
  - High line density

} (low frame rate)
- BUT.....
  - Poor temporal resolution

# Temporal Resolution/Image Quality

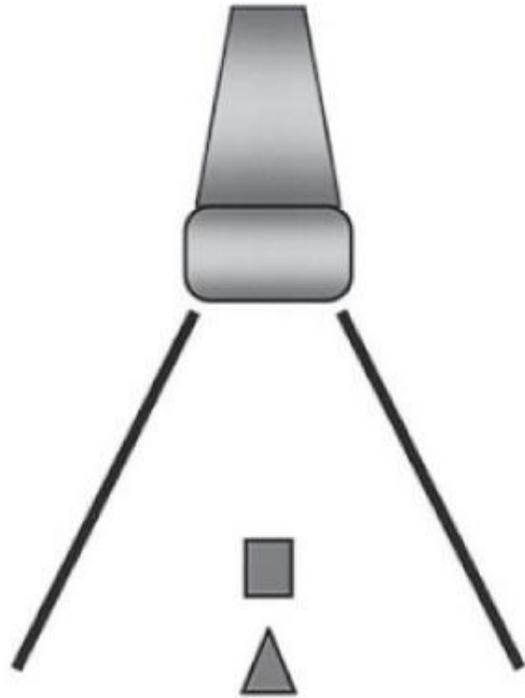
- To produce exceptional temporal resolution use:
  - Single focusing
  - Narrow field of view
  - Low line density

(high frame rate)
- BUT.....
  - Poor accuracy of image

# Temporal Resolution/Image Quality

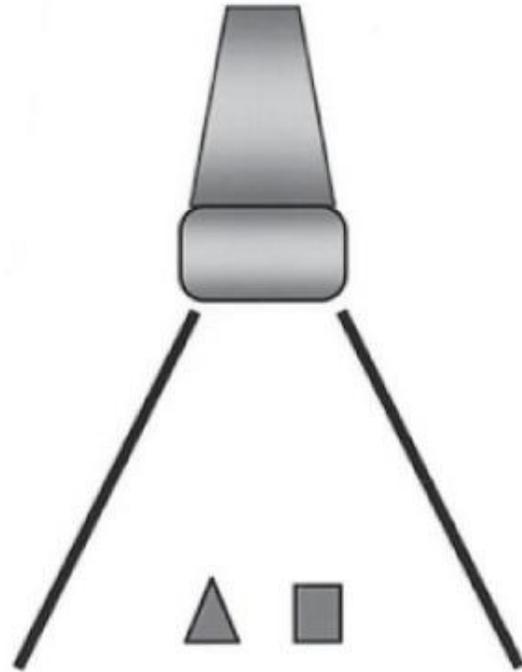
- As temporal resolution improves
  - Image quality may degrade
- As temporal resolutions degrades
  - Image quality may improve
- Increasing line density degrades temporal resolution
  - But improves spatial resolution
- Turning on multi-focusing degrades temporal resolution
  - But improves lateral resolution

## Axial resolution



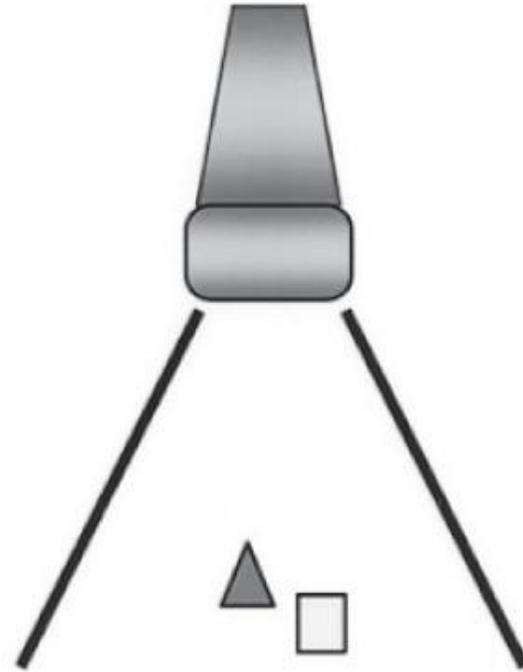
Pulse length  
Frequency

## Lateral resolution



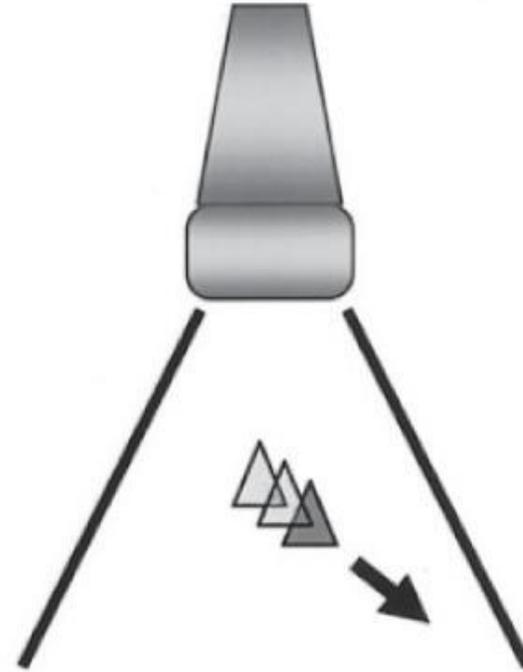
Beam width  
Depth  
Gain

## Contrast resolution



Pre processing  
Post processing  
Size

## Temporal resolution



Depth  
Sweep angle  
Line density  
PRF

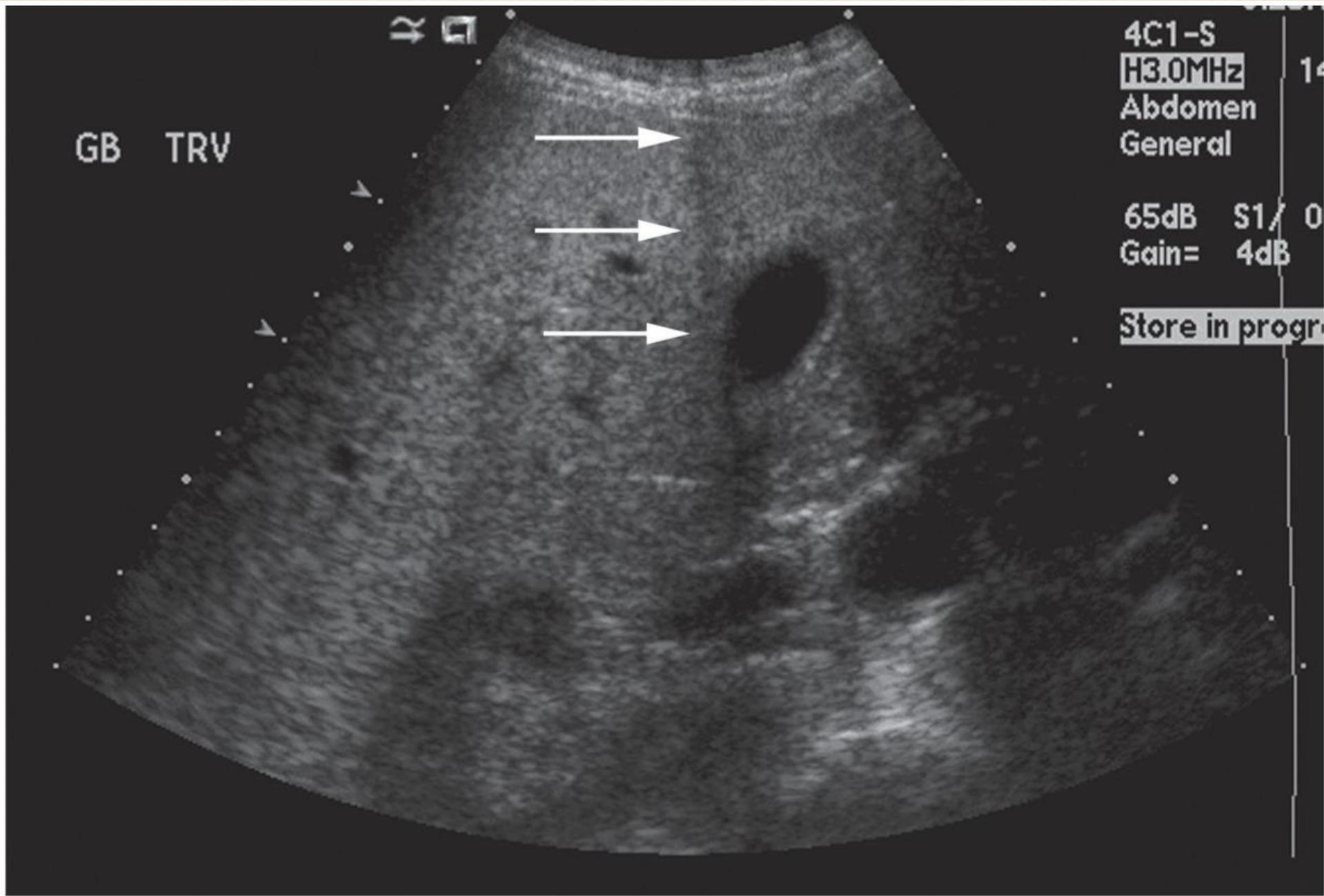
Primary  
determinants

# Transducer Care and Maintenance

- Proper handling of the transducer is essential in order to prevent damage to the cord, connector, and piezoelectric elements
- Transducers should be hung in the proper transducer holder on the equipment and never dangled over the handle of the machine
- Hanging the transducer improperly places undue stress on the cord and may damage the wires inside

# Transducer Care and Maintenance

- Likewise, dangling the transducer over the machine handle increases the risk of the transducer falling to the ground and potentially causing permanent and irreparable damage
- Both the transducer and power cords should be carefully draped so as to avoid rolling the machine over the cord as well
- When the cord or probe is damaged, it may appear on the screen as an area of dropout
- Any damage to the transducer or the cord should be immediately resolved



# QUESTIONS

---

In linear phased arrays, what is the firing pattern that focuses a sound beam?

- A. Electronic Slope**
- B. Electronic Curvature**
- C. Electronic Transmission**
- D. Electronic Reception**

Mechanical scanning produces pictures that are similar in shape to linear phased array images.

**A. True**

**B. False**

In linear phased arrays, what is the firing pattern that steers a beam up or down?

- A. Electronic Slope**
- B. Electronic Curvature**
- C. Electronic Transmission**
- D. Electronic Reception**

Which of the following transducers creates a rectangular shaped image?

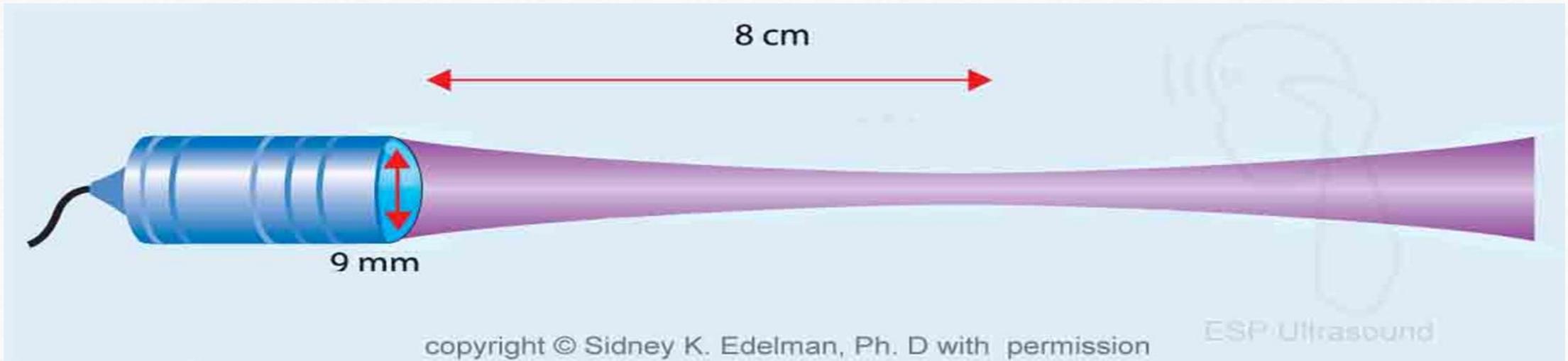
**A. Vector**

**B. Linear Sequential Array**

**C. Mechanical**

**D. Linear Phased Array**

What is the lateral resolution at a depth of 8 cm?



- A. 4 cm
- B. 4.5 mm
- C. 8 cm
- D. 9 mm

What is the lateral resolution at a depth of 16 cm?



- A. 4 cm
- B. 9 mm
- C. 8 cm
- D. 16 mm

When the number of cycles in a pulse increases (more ringing) while the frequency remains the same, the image quality:

- A. Improves**
- B. Degrades**
- C. Remains the same**

Name the synonyms for lateral resolution.

- **LATA:**

**Lateral**

**Angular**

**Transverse**

**Azimuthal**

Name the synonyms for axial resolution.

- **LARRD:**

**Longitudinal**

**Axial**

**Range**

**Radial**

**Depth**

Which of the following transducers has the best lateral resolution deep in the far zone?

- A. Lowest frequency/largest diameter**
- B. Highest frequency/largest diameter**
- C. Lowest frequency/smallest diameter**
- D. Highest frequency/smallest diameter**

All of the following decrease temporal resolution except:

- A. Lower frame rate**
- B. Deeper imaging**
- C. Multi-focus**
- D. Narrower sector**

A sonographer, using a phased array system, turns off the multi-focus feature. What is the most likely consequence of this action?

**A. Frame rate decreases**

**B. Temporal resolution degrades**

**C. Imaging depth increases**

**D. Temporal resolution improves**

Which of the following is consistent with improved temporal resolution?

- A. Color Doppler**
- B. More gray shade**
- C. More detail**
- D. Higher frame rate**

A sonographer adjusts an ultrasound scan to double the depth of view from 5 cm to 10 cm.

What happens to the frame rate?

**A.** It is halved

**B.** It doubles

**C.** It increases from 5 – 10 Hz

**D.** It is unchanged

The number of lines per frame and the frame rate determine the pulse repetition frequency.

**A. True**

**B. False**

Which of the following is most important in determining the frame rate of a system?

- A.** Depth of view
- B.** Dynamic range of the receiver
- C.** Transducer frequency
- D.** Transmitter output

When the frame rate is 30 Hz, how long does it take to create a frame?

**A. 30 sec**

**B. 3 sec**

**C. 0.3 sec**

**D. 1/30 sec**

A sonographer changes an images sector size from  $90^\circ$  to  $45^\circ$ . The frame rate remained unchanged. What else must have happened?

- A. Temporal resolution was doubled**
- B. Sector size was doubled**
- C. Line density was doubled**
- D. Imaging depth was halved**