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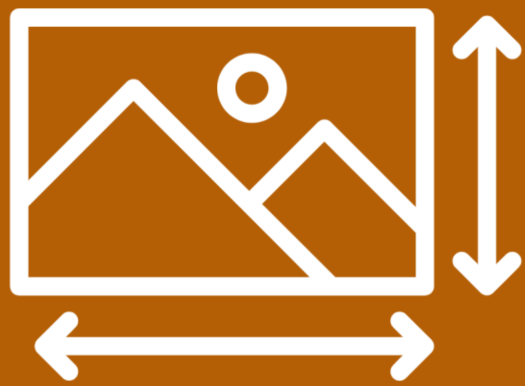

ARDMS Topic:
Ultrasound Transducers

Unit 10:
Resolution #1
(Axial & Lateral)

Sononerds Ultrasound Physics
Workbook & Lectures

Unit 10: Resolution #1 (Axial & Lateral)

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Unit 10: Resolution #1 (Axial & Lateral)

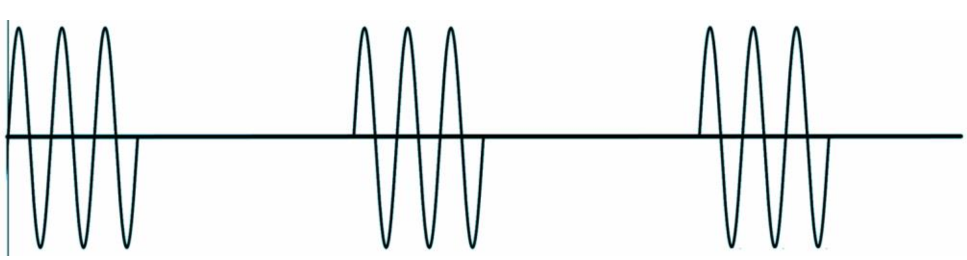
Resolution describes the way detail can be displayed. When we say something. When we say something has more,better or higher resolution, it means that it can create a more accurate display, therefore, higher resolutions are preferred for image accuracy.

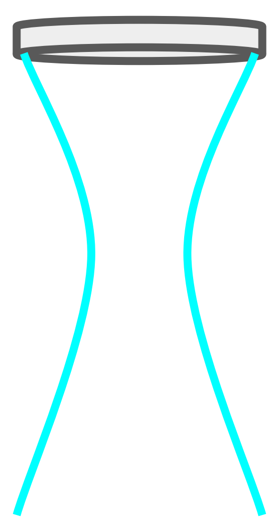
There are many types of resolution related to ultrasound:

- Spatial resolution, which is the dependent on the pixels of a monitor and scan lines in an image,
- Contrast resolution is the ability to differentiate between shade of gray,
- Temporal resolution that determines the accuracy of moving objects,
- Elevational resolution determines if we are accurately seeing a thin slice of anatomy with the ultrasound beam,
- Lateral resolution determines the accuracy of side by side structures being displayed and lastly,
- Axial resolution, which determines how accurately a system can display two reflectors that are parallel to the sound beam.

This lecture is going to focus on axial & lateral resolution. Throughout the first few units of this course, you may recall hearing the terms axial resolution and lateral resolution.

Axial resolution is highly dependent on the spatial pulse length, where lateral resolution is dependent on the beam width.



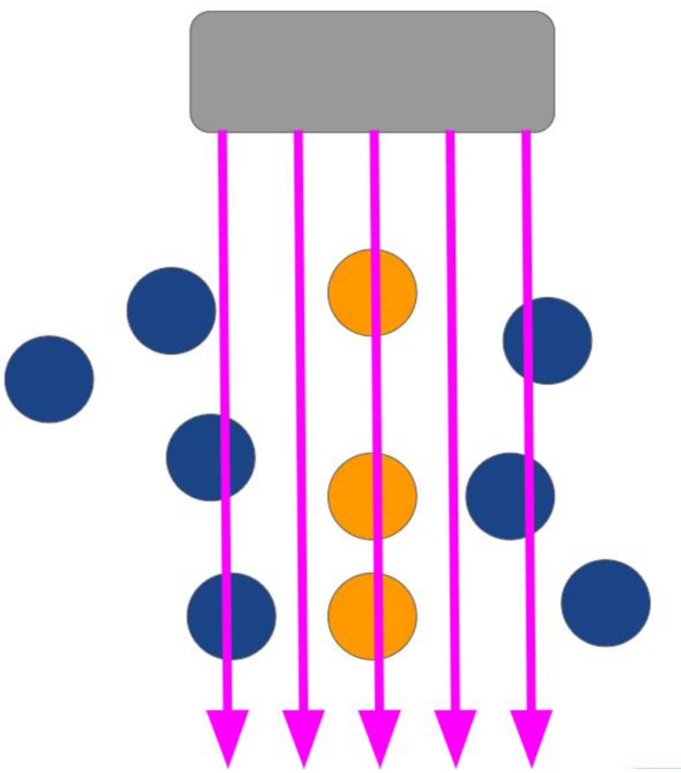


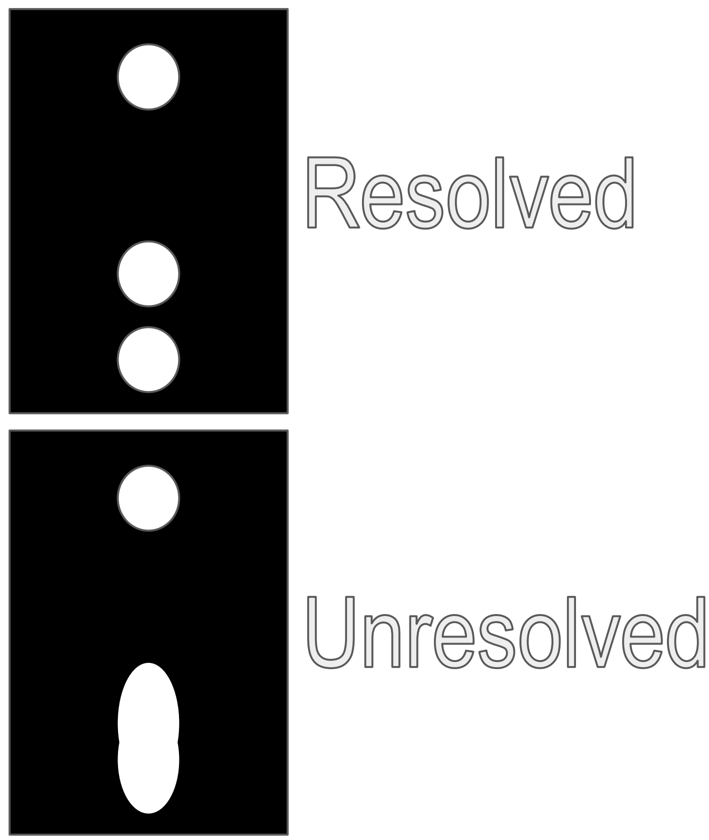
Section 10.1 Axial Resolution

- **Axial resolution is the machine's capability to accurately image reflectors that are PARALLEL to the sound beam.**

When sound beams are emitted from a transducer, the pulse is sent directly from the face of transducer. The sound beam travels into the body and interacts with reflectors. It is the reflectors that sit within the length of the pulse, or run in the same direction of the pulse that we consider to be parallel to the beam. Another way we can think of this is are reflectors that are sitting in front or in back of one another rather than side by side.

In this example, the orange "reflectors" are parallel with the sound beam and how accurately they are displayed will be determined by axial resolution.





An accurate display of these reflectors would show 3 separate reflectors.

- **When reflectors are displayed appropriately we call them resolved.**

An inaccurate display would show the reflectors incorrectly, showing too few and incorrect size.

- **When reflectors are displayed incorrectly we them unresolved.**

10.1.1 Calculating Axial Resolution

- ➔ **Axial resolution is determined by the spatial pulse length.**

Recall that spatial pulse length is the distance that a pulse takes up in space. If we could see the spatial pulse length, we could get out a tiny ruler and measure it.

But we can't.

However, we can calculate SPL and therefore calculate the axial resolution.

As a reminder, this is the formula for SPL:

$$SPL\ (\mu s) = \ \#\ cycles\ \times \lambda\ (mm)$$

And here is the formula for Axial Resolution:

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

Note that SPL is measured as a distance. So is axial resolution. The average axial resolution of imaging ultrasound systems is **0.05 mm to 0.5 mm.**

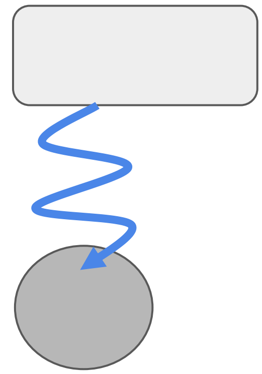
- ➔ **When axial resolution has a LOW numerical value, the better the axial resolution is.**

This is because axial resolution

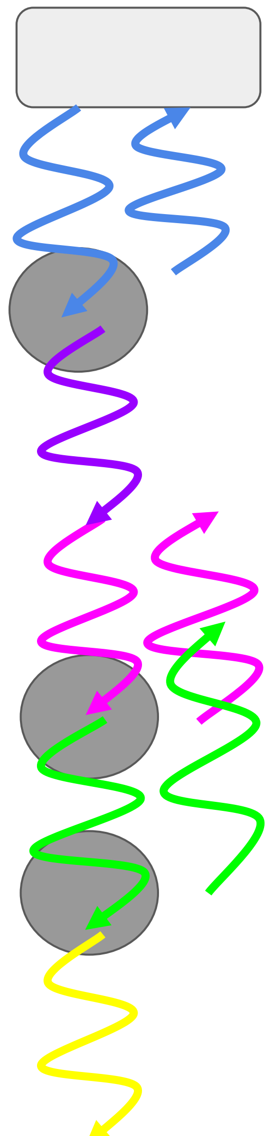
- ➔ **Tells us the minimum distance 2 reflectors must be when parallel with the beam to be displayed as resolved reflectors.**

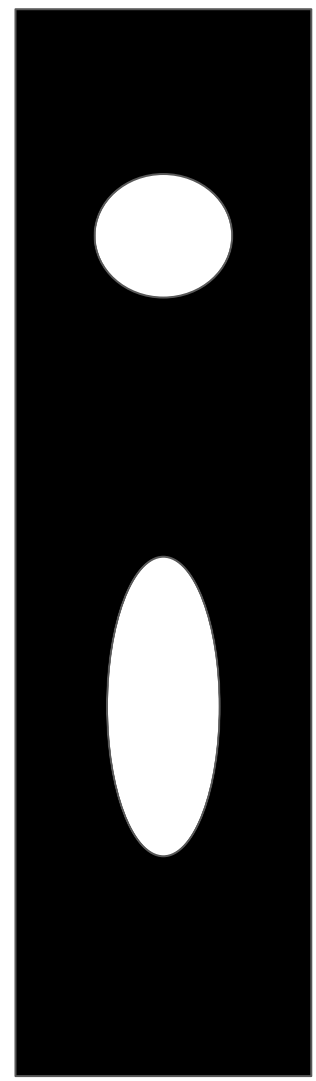
Let's take a look at an over simplified look at what is happening during the pulse.

A pulse is sent out. And begins propagating into the tissue.



The first reflector will send sound back, and some of the sound energy of the pulse keeps going.





When that echo gets back to the machine it recognizes it as an independent reflector.

At the next reflector, some is sent back and some keeps going.

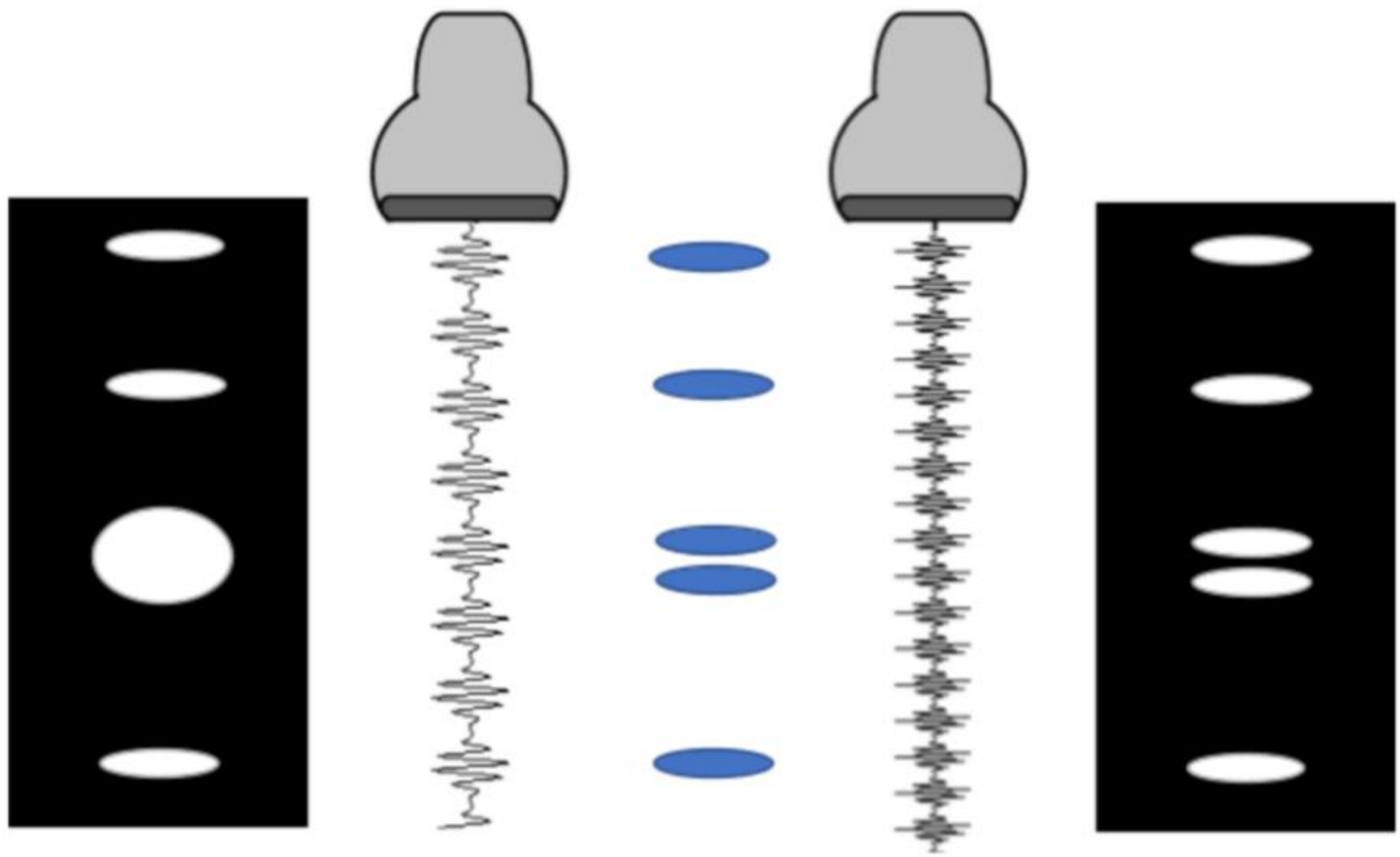
This time though, if the next reflector is super close, its echo is going to **overlap** with the last echo right before it.

When both of the echoes return to the machine at the same time, the machine isn't going to know that they are separate echoes, so it will treat them as one and display it as such

- **Note that SPL remains the same as the pulse propagates and so does axial resolution.**

Let’s take a look at an example with some numbers. If the SPL of a pulse is 4 mm, the axial resolution of that pulse is 2 mm. This means that the reflectors need to be at least 2 mm apart to shown as single reflectors, otherwise they will be shown a a larger “blob.” .

If we can shrink the SPL to 2 mm, making the axial resolution 1 mm, the reflectors now only have to be 1 mm apart to be shown as single reflectors.



By knowing our formula and looking at the examples, we can now say that axial resolution improves with **Low numerical values**, **which are created by shor SPLs.**

10.1.2 Improving Axial Resolution

To improve the detail in our image, we want to optimize the axial resolution. But this cannot be done with a simple knob on the machine because axial resolution is **not adjustable.**

Instead, we need to look closer at the physics behind axial resolution so we can make better choices about our equipment.

Recall that SPL was one of those goofy parameters that is determined by the source and the medium. So for ultrasound that means it is tied to the frequency and manufacturing of the transducer as well as the soft tissue it travels through and if it's true for SPL, it's true for axial resolution too.

In fact, there is another formula that shows us this. In soft tissue:

$$Axial\ Resolution\ (mm) = \frac{0.77\ \times \#\ of\ cycles}{f\ (MHz)}$$

The 0.77 referring to 1.54 mm per microsecond of travel divided by two.

By analyzing this formula, we can see that:

- ➔ **Axial resolution and frequency are inversely related**
- ➔ **Axial resolution and # of cycles is directly related**

To improve our axial resolution, we want to increase the frequency.

Increasing the frequency, give us short wavelengths → short wavelengths give us short SPLs → short SPLs improve axial resolution.

Lower transducer frequencies create long wavelengths, which will degrade our axial resolution. As a sonographer you need to balance choosing the transducer with the highest frequency to improve resolution with a low enough frequency for sound penetration to image your target anatomy.

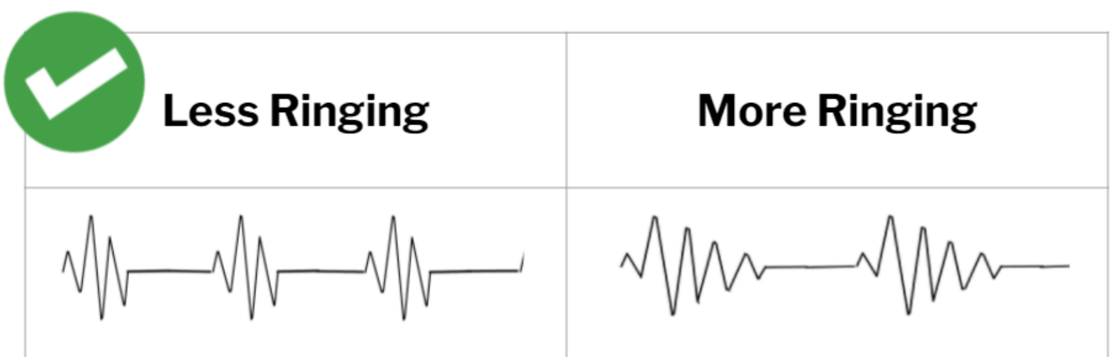
High Frequency	Low Frequency
	

The other way to improve axial resolution is to reduce the number of pulses. Sonographers don't choose the number of cycles in a pulse though, that is dependent on how the transducer is made.

When a transducer is made with backing material, it keeps the PZT crystal from ringing. They make a short chirp, with fewer cycles in the pulse → Less cycles in the pulse mean, short SPLs → short SPLs mean improved axial resolution.

Without the backing material, the PZT crystals can continue to ring, or make more cycles in the pulse, this makes the pulse long and degrades axial resolution.

So even though we can't choose the cycles per pulse, you need to know that less ringing and fewer cycles per pulse makes for better axial resolution.



Final thoughts on axial resolution:

When presented with a choice of transducers, choose the transducer with the highest frequency and the fewest cycles.

Current texts tell us there are alternative names for axial resolution → Longitudinal, Axial, Range, Radial & Depth. They all essentially mean the same thing so - parallel with the sound beam. Some newer texts omit this information stating that it is not covered on the boards anymore. I still want you to have it depending on the study material you use later.

10.1 Practice

Which scenario has better axial resolution?

A 5 MHz probe that produces pulses with 3 cycles per pulse

A 5 MHz probe that produces pulses with 4 cycles per pulse

Which scenario has better axial resolution?

A 5 MHz probe that produces pulses with 3 cycles per pulse

A 12 MHz probe that produces pulses with 3 cycles per pulse

Which scenario has better axial resolution?

Pulse with an SPL of 2 mm

Pulse with an SPL of 1 mm

Which scenario has better axial resolution?

Wave with 0.2 mm wavelength

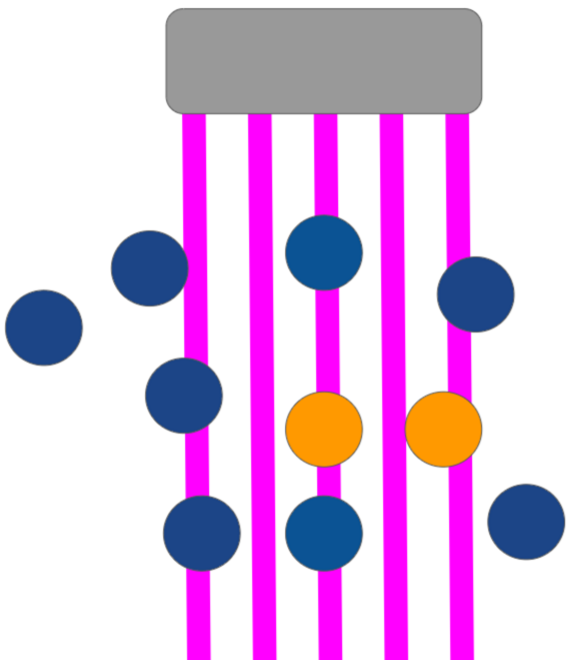
Wave with 0.4 mm wavelength

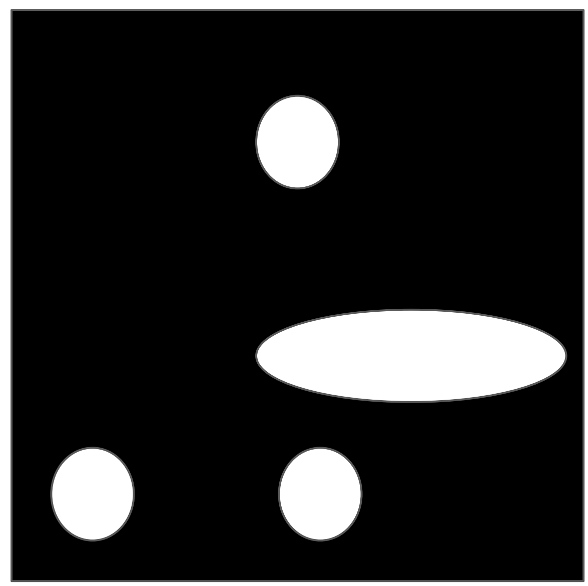
Section 10.2 Lateral Resolution

- **Lateral resolution is the machine's capability to accurately image reflectors that are PERPENDICULAR to the sound beam.**

Remember that we learned the beam has a width when it leaves the transducer, it narrows at the focus and then diverges again at the far field. The reflectors can sit parallel to the beam (as we learned with axial resolution) and they sit perpendicular to the beam. Reflectors that are perpendicular to the beam sit side by side or next to one other.

The orange reflectors are examples of "reflectors" that are perpendicular to the sound beam.





Depending on how the reflectors are displayed, they can still be considered resolved or unresolved.

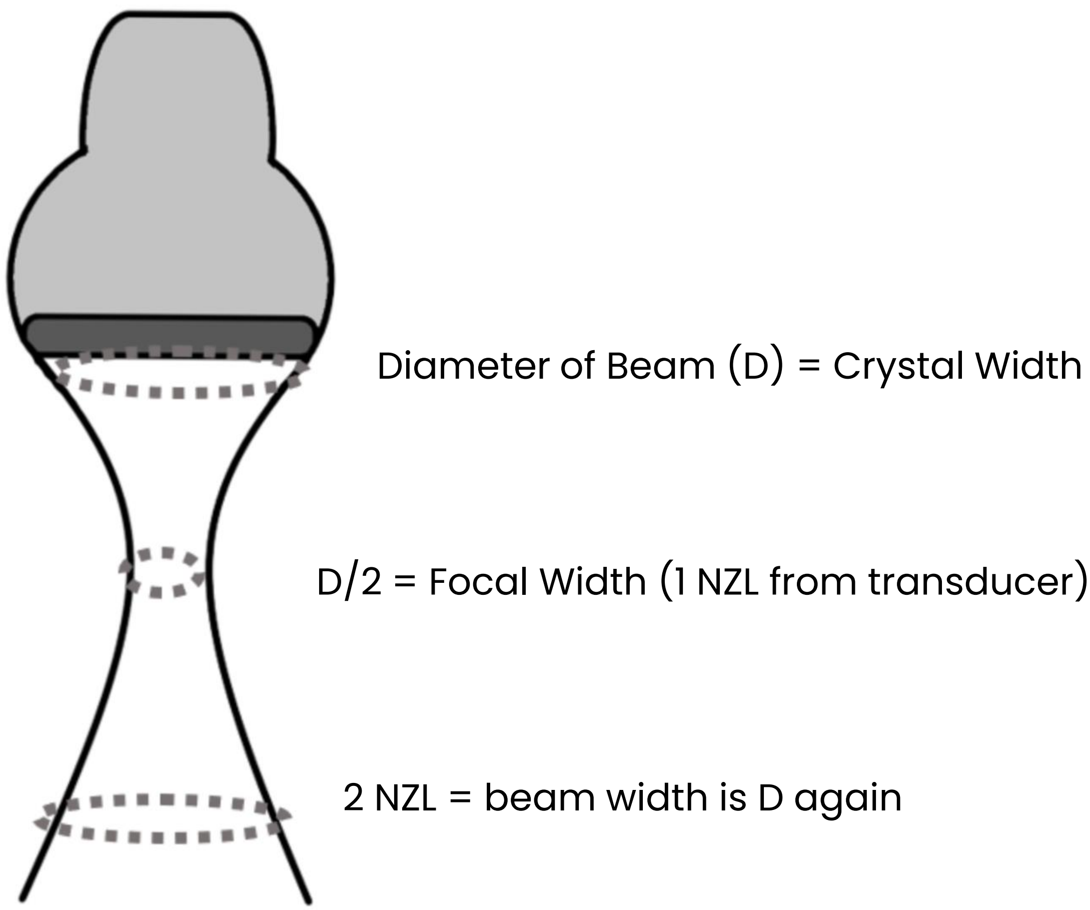
When they are unresolved and referring to lateral resolution, it is also called:

- **Point spread artifact**

The unresolved reflectors are wide, spreading across the image.

10.2.1 Calculating Lateral Resolution

When we learned about the anatomy of a sound beam we saw that at different depths, the beam width changed and that it could be calculated.



The good news is that the formula for lateral resolution is also pretty easy:

$$Lateral\ Resolution\ (mm) = Beam\ Width\ (mm)$$

The smaller the numerical value, the **better** the lateral resolution is because this is the distance 2 structures need to be from one another to be represented as two separate structures on the monitor. The smaller number means two objects can be closer together.

10.2.2 Improving Lateral Resolution

Improving lateral resolution requires a little bit more of nuanced discussion. Remember we have been talking about an "unfocused" beam, meaning that it has no external apperati to help focus the beam like a lens, curved element or electronic focusing.

In this scenario, the beam has a natural focus due to Huygens' Principle and will narrow to ½ the diameter of the crystal. When asked to calculate lateral resolution, this is the type of transducer that you are considering.

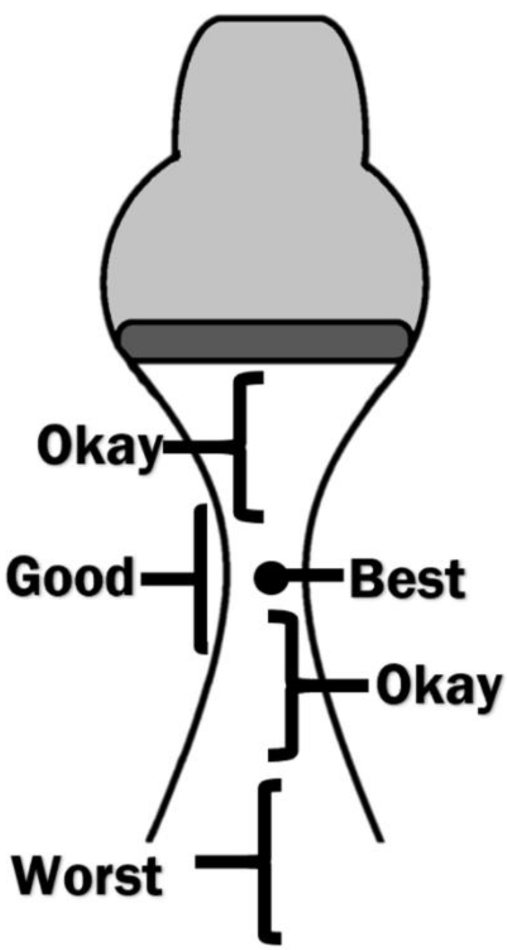
WIth this type of transducer, lateral resolution is fixed because the focus is fixed. The only way to change it is to change to a new transducer with a different diameter or frequency.

The location of the focus is important because:

- ➔ **Lateral resolution is BEST at the focus.**

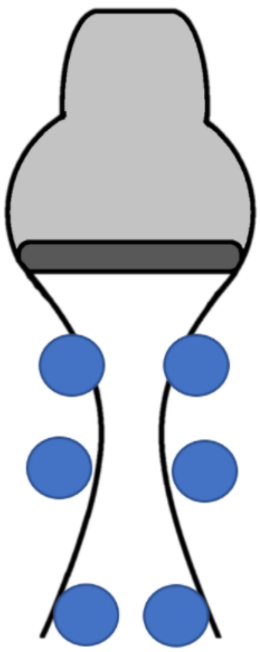
This is where the beam is narrowest and has the lowest numerical value.

In the unfocused beam we will see that lateral resolution is:

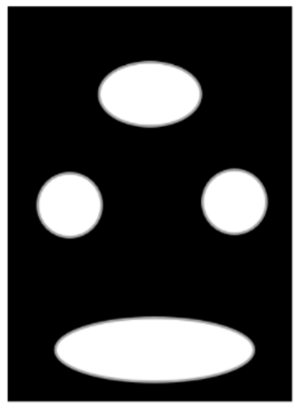


- ➔ **Best at the focus**
- ➔ **Good in the focal zone**
- ➔ **Okay throughout the near zone**
- ➔ **Worsens in the far zone the further from the focal zone the beam travels because of a diverging beam**
  - ◆ It's getting wider, so the numerical value of lateral resolution is getting higher.

In the unfocused transducer, we might see something like this:



Reflectors



Display

If D = 10 mm, then:

At the crystal face, structures must be at least 10 mm apart to be displayed correctly.

At the focus, structures must be at least 5 mm apart.

At 2 NZLs, structure must be at least 10 mm apart.

Beyond this point structures will need to be more than 10 mm apart.

By using numbers, we can see that as the beam diameter changes, so does the lateral resolution because

➔ **Beam diameter = Lateral resolution**

We also see that in the far field, especially after the focal zone:

➔ **Lateral resolution worsens in the far field**

Some other points about lateral resolution:

Lateral resolution is usually worse than axial resolution. The pulses are much shorter than the width of the beam.

Just like axial, some texts have many names for lateral resolution: lateral, azimuthal, transverse and angular

10.2 Practice

Which scenario has better lateral resolution at the focus?

20 mm diameter crystal

15 mm diameter crystal

Which scenario has better lateral resolution in the far field?

High frequency transducer

Low frequency transducer

Which scenario has better lateral resolution in the far field?

Large diameter transducer

Narrow diameter transducer

What is the minimum 2 reflectors must be from one another to be displayed correctly when imaged with an unfocused, single element transducer that is 8 mm in diameter at the:

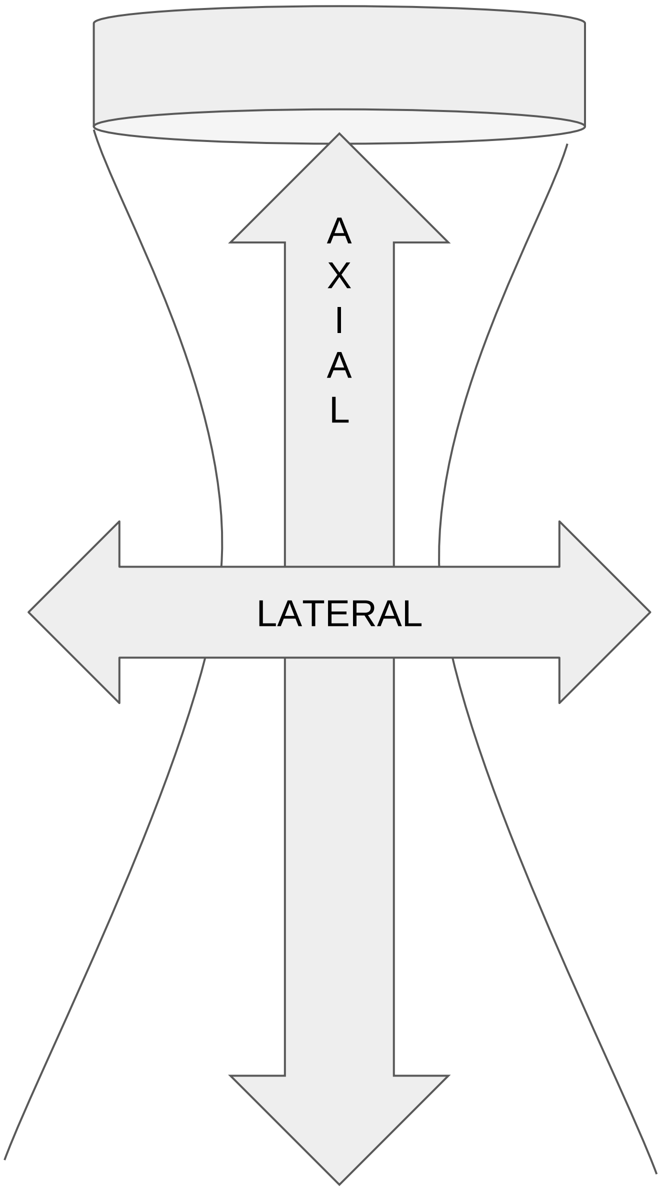
Start of the near field?

Focus?

2 NZLs?

Section 10.3 Clinical Discussion

Comparing axial resolution and lateral resolution helps to explain how the the sound beam acts in 2 planes. It also helps us to better understand why we choose the transducers that we do for our exams.



Lateral Resolution:

- Perpendicular to sound beam
- Dependent on beam width
  - Near field is better with smaller diameter transducers
  - Focus is better with smaller diameter transducers
  - Far field is better with high frequencies and large diameters

$$Lateral\ Resolution\ (mm) = Beam\ Width\ (mm)$$

Axial Resolution:

- Parallel to sound beam
- Dependent on pulse length
  - Whole image improves with high frequency
  - Whole image improves with few pulses

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

We have now learned that **high frequencies:**

- Improve both axial and lateral resolution
- Have deeper focal depths
- Have less divergence

BUT

- They attenuate very quickly, therefore providing very little imaging depth

Low frequencies:

- Degrade both axial and lateral resolution
- Have shallow focal depths
- Diverge more in the far field

BUT

- Do no attenuate very quickly, therefore providing more imaging depth

To optimize the image in regards to axial and lateral resolution, the sonographer should:

➔ **Always choose the highest frequency that will allow us to see all the anatomy that we need.**
➔ **Use modern tools to adjust the focus appropriately.**

Section 10.4 Focusing

In an unfocused beam, there is a still a natural focus that occurs. This natural focus is rather inadequate in the clinical setting.. Therefore, there are 3 types of focusing that have been utilized in transducer construction to improve the focus of a beam:

➔ **Lens - external fixed focus**
➔ **Curved elements - internal fixed focus**
➔ **Electronic focusing - adjustable**

10.4.1 Lenses

Using an acoustic lens is very similar to how glasses work. By placing a lens in the path of the sound beam it will change the path of the wavelets (refraction) to create a more narrow focus than without.

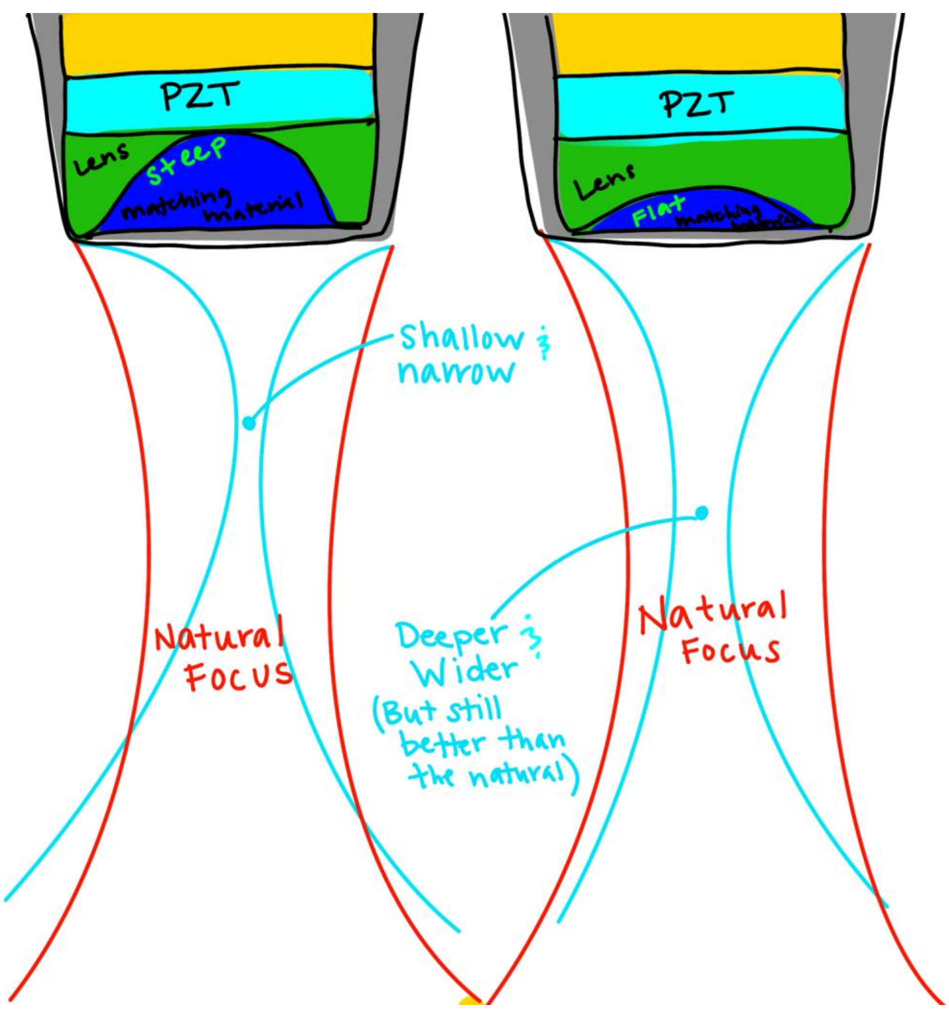
The use of a lens is typically only seen with **single element transducers.** It is placed in between the PZT crystal and the matching material. This unfortunately adds another impedance through which the sound must travel before getting to the skin.

The curvature of the lens determines the depth and width of the focus.

- ➔ **Very steep curves = shallow, narrow focus**
- ➔ **Flatter curves = deeper, wider focus**

The lens is built into the transducer construction, so this is classified as an **external, fixed focus, that cannot be changed**, unless switching transducers.

The lens can only make the focus more shallow. The degree to which it focuses is determined by the frequency, aperture and focal zone length.



10.4.2 Curved Elements

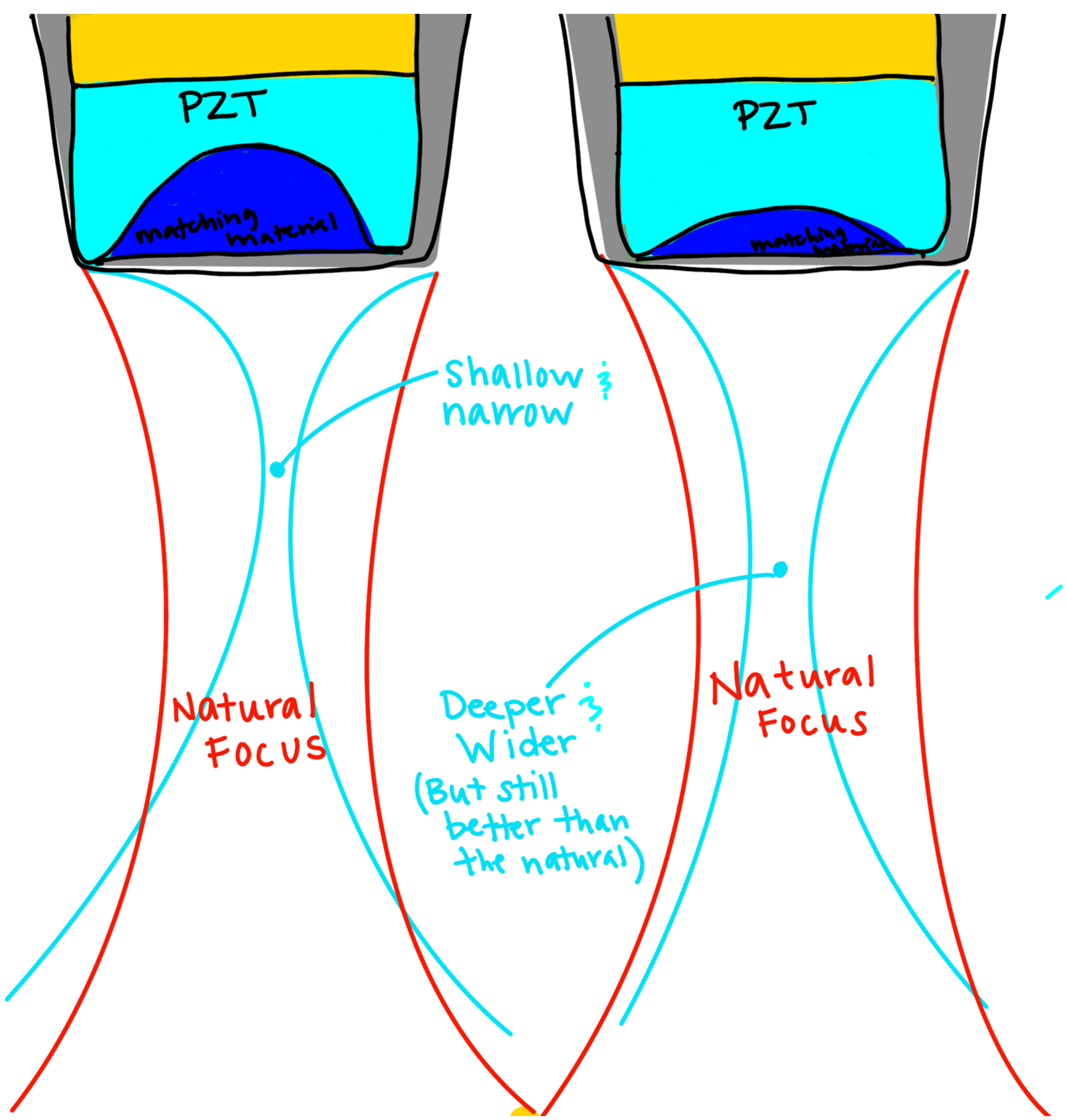
The curved element is the more popular form of **fixed focusing**. The PZT material is more flexible and it removes the extra impedance in between the PZT and matching layer.

Sound will leave directly from the PZT surface. If the surface is curved then sound will leave at different angles from the surface,

As with the lens, the curve of the PZT material also matters:

- ➔ **Very steep curves = shallow, narrow focus**
- ➔ **Flatter curves = deeper, wider focus**

The curved element is built into the transducer construction, so this is classified as an **internal, fixed focus, that cannot be changed**, unless switching transducers.



10.4.3 Electronic Focusing

Electronic focusing is the most common, modern way in which we focus the ultrasound beam. It's main benefit is that

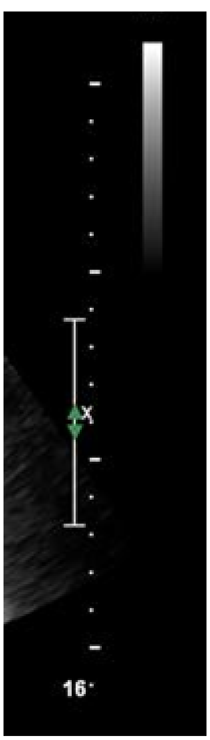
- **Electronic focusing is adjustable by the sonographer!**

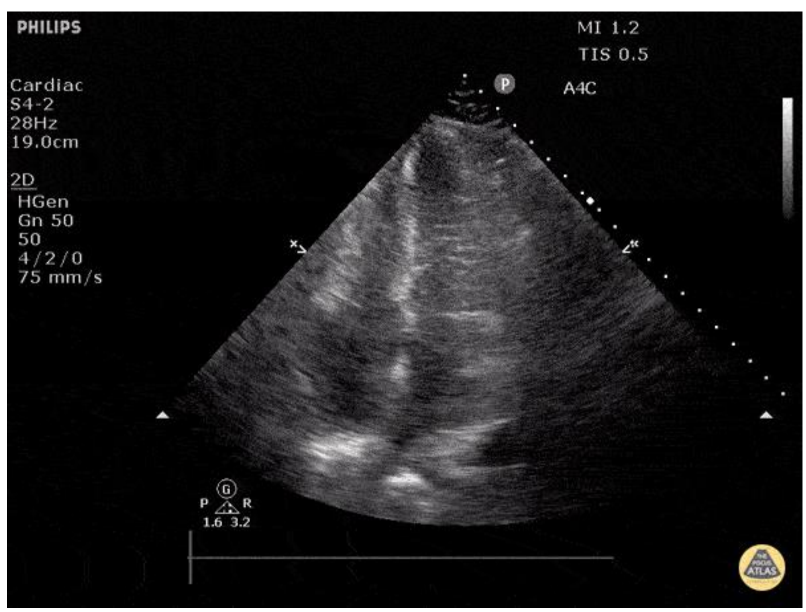
Electronic focusing can only be used on **multi-element transducers.** Which are also known as **arrays.**

Each element in an array transducer is connected to a wire. The machine will activate the elements using a very specific voltage pattern to focus the beam. The machine setting will determine the pattern, therefore, the sonographer can changed the focus by turning a knob, telling the machine to send the pattern that matches that setting.

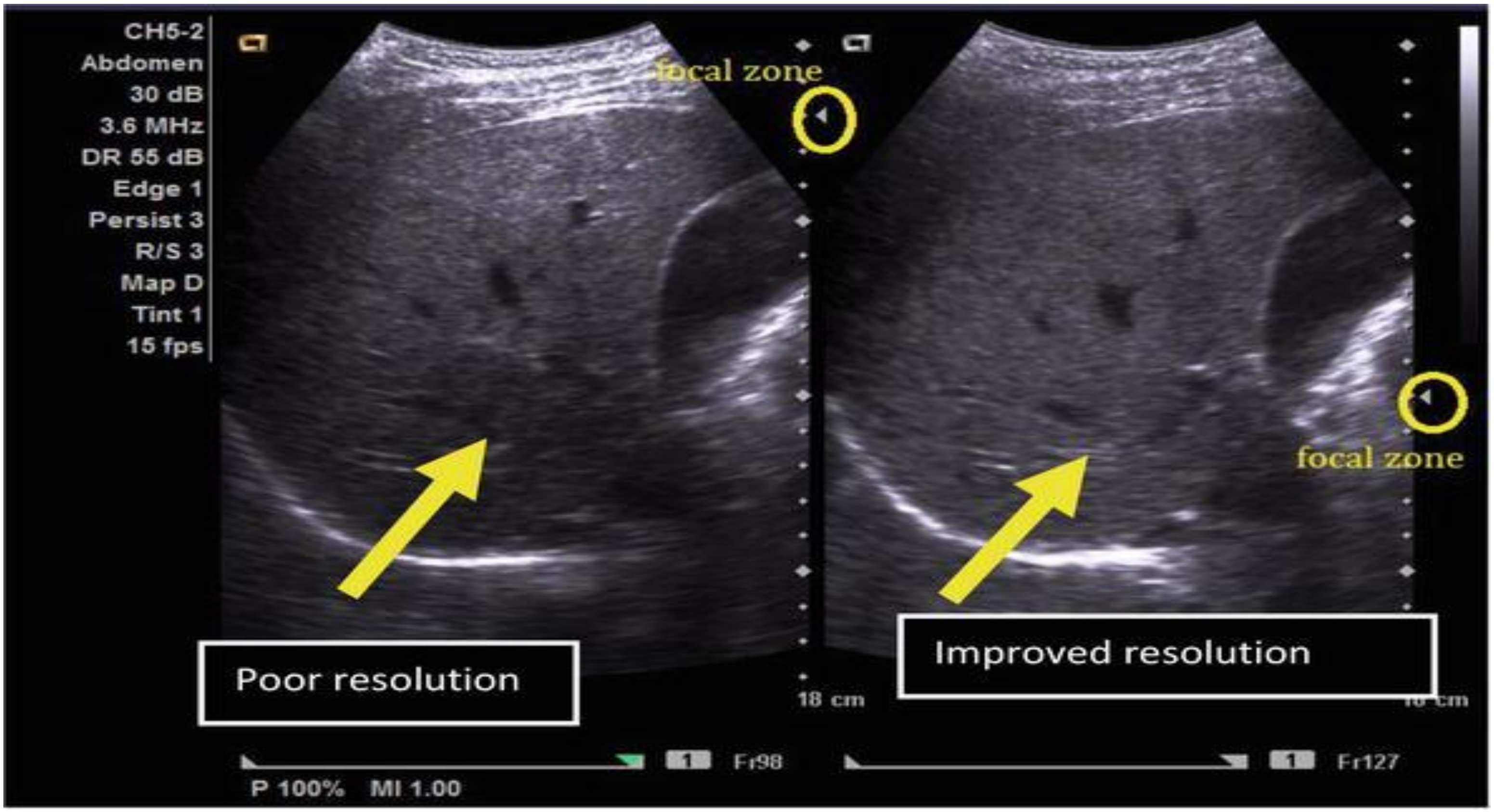
The focus is usually indicated by a small symbol next to the sector. A larger "bar" will indicate the focal zone, remember the focus is in the center of the focal zone.

This helps the sonographer know where to place the focus to optimize the image's lateral resolution.   Your focus should be placed at or just below the area of interest.





Wiafe, Y. A., & Badu-Peprah, A. (2019). The Influence of Ultrasound Equipment Knobology in Abdominal Sonography. In *Essentials of Abdominal Ultrasound*. IntechOpen.



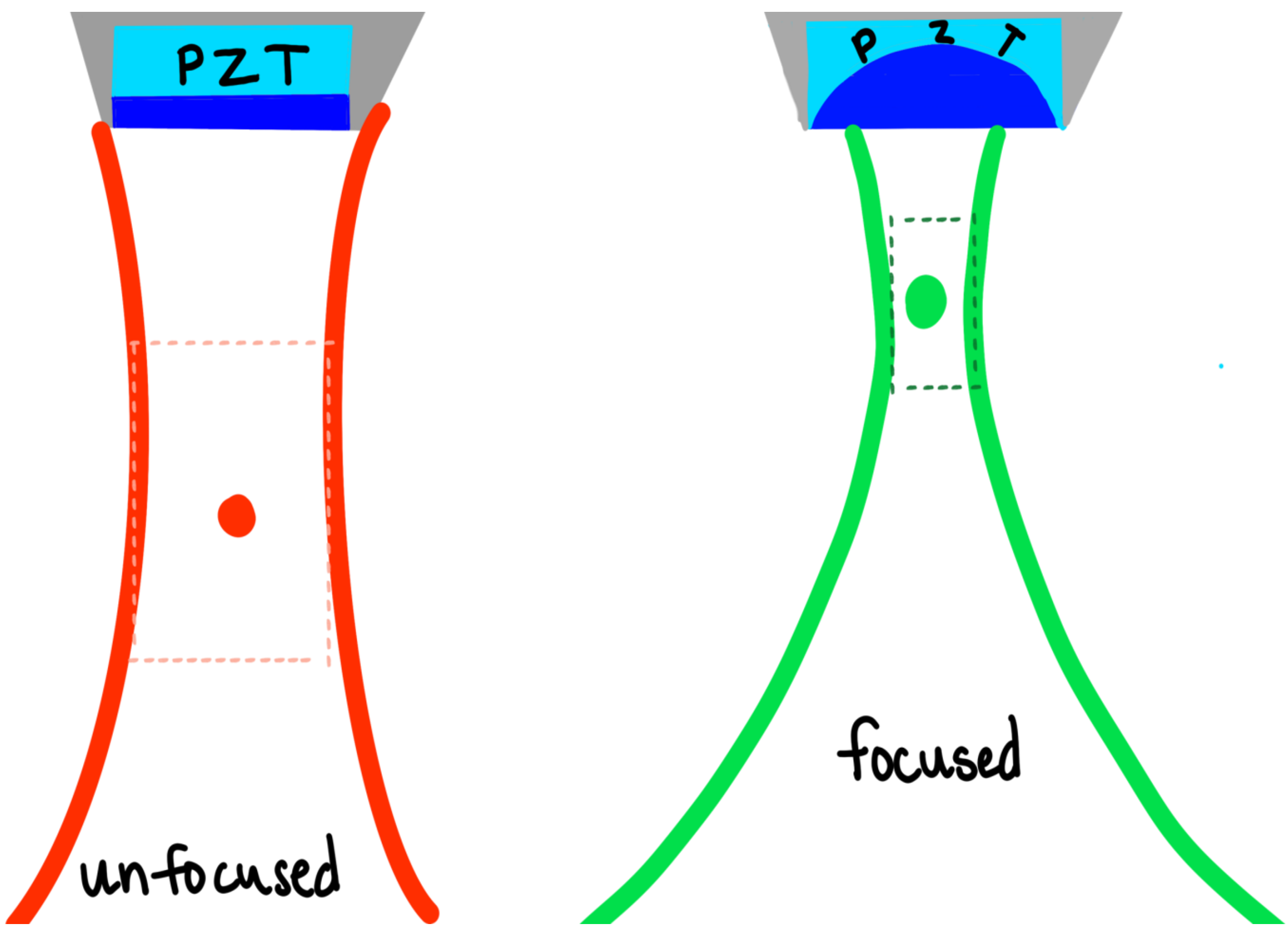
Notice how the detail changes by moving the focus into a lower position. It is making the beam narrower and concentration the power more in this area.

There will be more about electronic focusing when we discuss array transducers in a later unit.

Section 10.5 Effects of Focusing

When a beam is focused, it changes how it behaves in space. There are four effects of focusing that we see:

- **The beam diameter in the near field is smaller than the element.**
  - Unfocused beams start as the same size.
- **The focus moves closer to the transducer, shortening the NZL.**
  - Unfocused beams will have deeper natural focuses.
- **The beam diverges quickly after the focal zone**
  - Unfocused beams diverge at a smaller angle and have better far field lateral resolution by comparison.
- **The focal zone size is reduced in length and diameter.**
  - Unfocused beams have longer and wider near zone lengths by comparison.

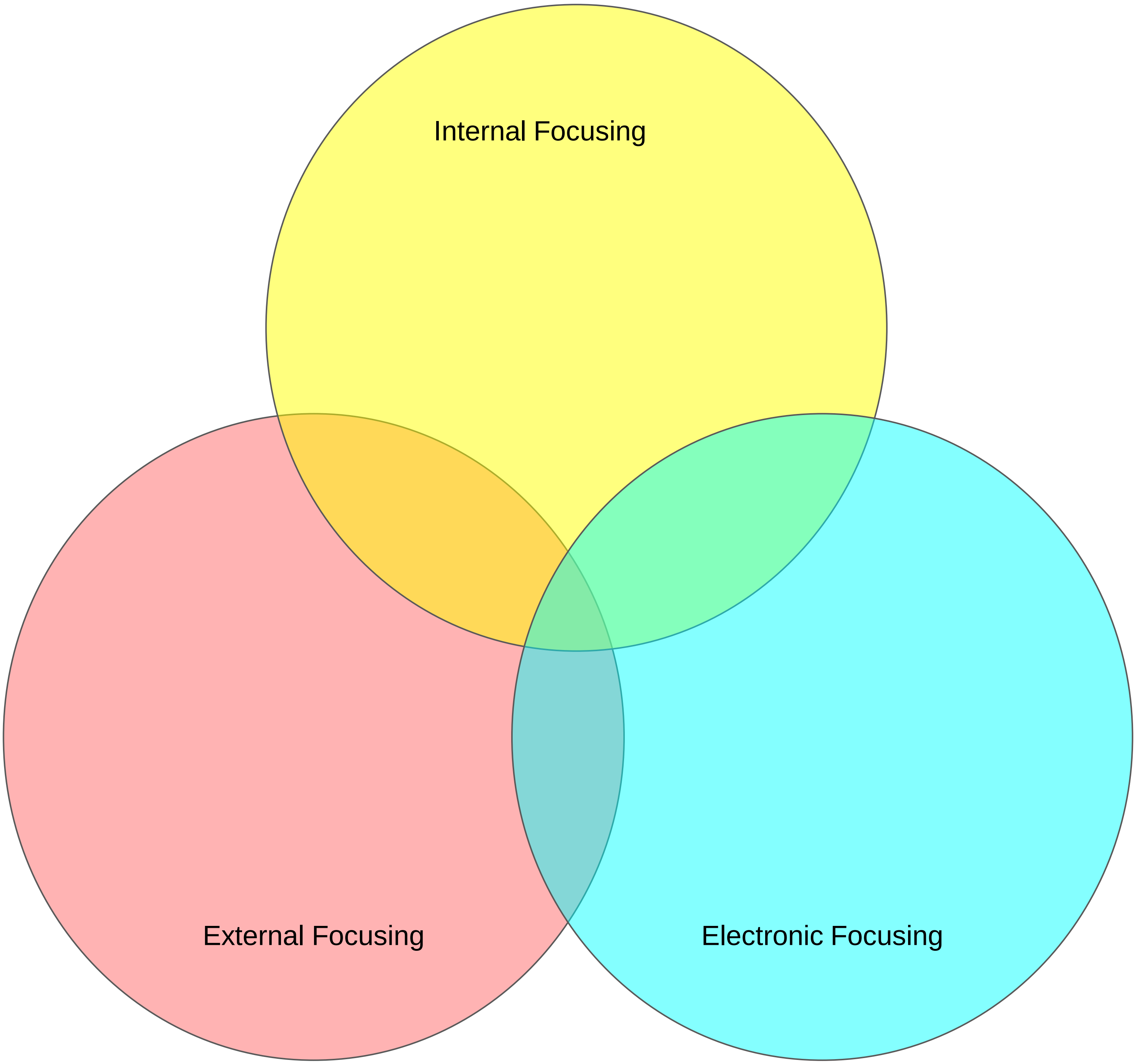


Section 10.6 Activities ← Link to Answers

1. For the following statements, type an A next to those that refer to Axial Resolution and an L next to those that refer to Lateral Resolution.

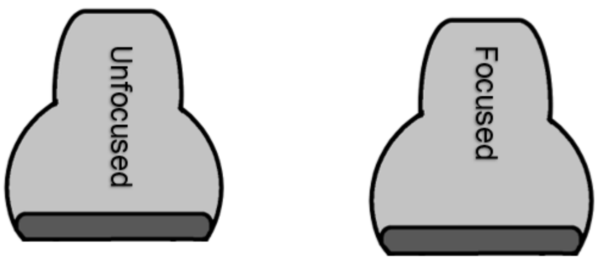
	Also known as transverse resolution		Is determined by the SPL
	Improves throughout the whole image with higher frequency		Improves with high frequencies in the far field
	Determines how far reflectors need to be apart when parallel to the sound beam		Determine how far things need to on top or front to back of one another
	Also known as azimuthal resolution		Changes with depth
	Best at the focal zone		Also known as range resolution
	Determines how far things need to be when perpendicular to the sound beam		Determines how far reflectors need to be when side by side
	Also known as angular resolution		Improves with less ringing
	Also known as longitudinal resolution		Determined by the beam width
	Also known as radial resolution		Is better in the near field with a small diameter crystal

2. Sort the statements to match the type of focusing. If it applies to more than one area, place the statement in the overlap.



- Uses a curved PZT crystal
- Uses a lens in front of the PZT
- Is dynamic and adjustable
- Uses system components to focus
- Is fixed and cannot be changed
- Seen with multiple element transducer
- Improves lateral resolution

3. Move the beam to the correct transducer. What are the 4 effects that occur when a beam is focused?



1	
2	
3	
4	

4. Put the star next to the pulse with the better axial resolution:

A 5 MHz probe that produces pulses with 3 cycles per pulse		A 5 MHz probe that produces pulses with 4 cycles per pulse
A 5 MHz probe that produces pulses with 3 cycles per pulse		A 12 MHz probe that produces pulses with 3 cycles per pulse
A probe with a Q-factor of 0.1		A probe with a Q-factor of 3
Pulse with an SPL of 2 mm		Pulse with an SPL of 1 mm
Wave with 0.2 mm wavelength and 4 cycles per pulse		Wave with 0.4 mm wavelength and 4 cycles per pulse

Section 10.7 Nerd Check!

1. What is resolution?
2. What are some types of resolution?
3. What are lateral and axial resolution dependent on?
4. What is axial resolution?
5. What does it mean to be parallel to the sound beams.
6. What are reflectors called when they are shown as discrete objects?
7. What are reflectors called when they are shown as an incorrect single object?
8. What determines spatial pulse length?
9. What determines axial resolution?
10. What unit is axial resolution in?
11. What is the formula for axial resolution?
12. If a machine has an axial resolution of 2 mm, what does this mean?
13. What happens to the echoes returning to the machine that the machine cannot tell them part
14. Does axial resolution change as the wave propagates?
15. What the minimum distance two reflectors must be to be resolved with an SPL of 4 mm? WIth 3 mm? With 2 mm? With 1 mm?
16. Is axial resolution adjustable?
17. What 2 things is axial resolution related to and how so?
18. Why do high frequencies create better axial resolution?
19. WHy do fewer pulses create better axial resolution?
20. What helps create less ringing/fewer pulses?
21. What are the other 4 synonyms for axial resolution?
22. What is lateral resolution?
23. What does it mean to be perpendicular to the sound beam?
24. What is the name for the widening of reflectors in the setting of poor lateral resolution?
25. How can we calculate the beam width?
26. How does beam width relate it lateral resolution?
27. What unit is lateral resolution in?
28. Where is lateral resolution best?
29. Why is lateral resolution bad in the far field?
30. Which resolution is usually better?
31. What are the 3 synonyms for lateral resolution?

33. How does a high frequency transducer affect us clinically?
34. How does a low frequency transducer affect us clinically?
35. How should we decide what transducer to use?
36. What are 3 types of focusing that we can use?
37. What does it mean to use a lens to focus the beam?
38. How does the curvature of the lens affect the beam?
39. Can lens focus be changed?
40. What does it mean to use a curved element?
41. Which is used more often, lens or curved element?
42. How does the curvature of the element affect the beam?
43. What is the difference between internal and external?
44. Can focusing with a curved element be changed?
45. What is electronic focusing?
46. Is electronic focusing adjustable?
47. What type of transducers can use electronic focusing?
48. What is an array transducer?
49. Why do we want our focal point/zone at or below the area of interest?
50. What are the 4 things that focusing a beam does and how does it compare to the unfocused beam?