

**ARDMS Topic:
Ultrasound Transducers**

**Unit 9:
Beam Anatomy**

**Sononerds Ultrasound Physics
Workbook & Lectures**

Unit 9: Beam Anatomy

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Unit 9: Beam Anatomy

[Entire Unit 9 Lecture:](#)

Sononerds
in the classroom



Unit 9: Beam Anatomy

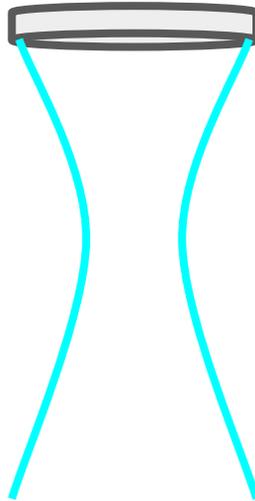
Unit 9: Beam Anatomy

Just as we discussed the anatomy of the transducer using a simple, single element, we will use the single element transducer to discuss how an ultrasound beam looks in space.

Note that this is overly simplified for initial discussion, we will add some more things to consider in regards to more modern transducers at the end of the unit.

For the time being though, the following diagrams are referring to a single element transducer, that is operating as a continuous wave.

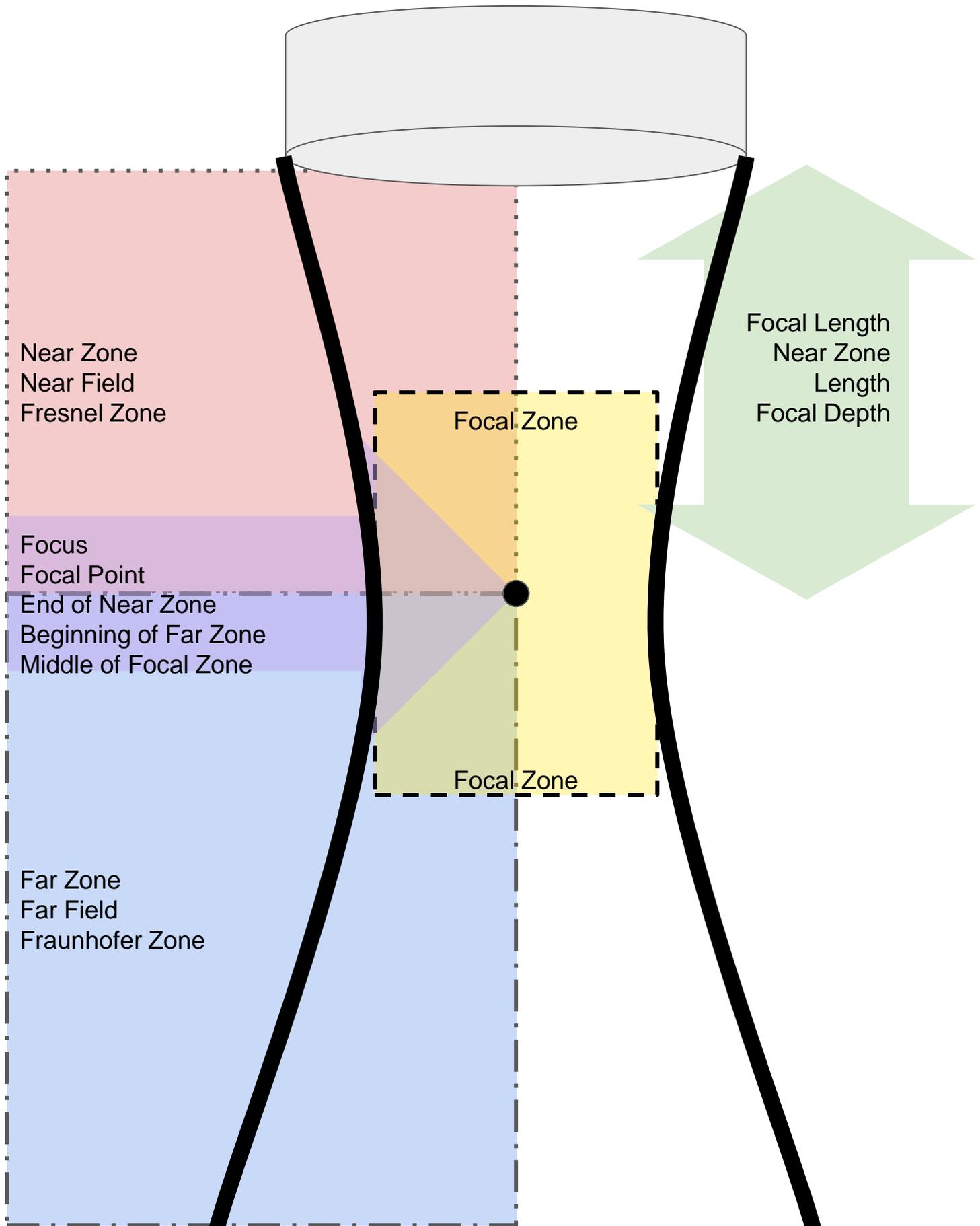
A single element transducer creates a beam that changes shape as it moves away from the transducer. It will begin as the same size as the element, converge to a natural focus and then diverge again in the far field. Diverge means to widen, which it will do so indefinitely until it attenuates.



As we learn about sound beam anatomy focus (pun intended) on:

- The names of the areas within a sound beam
 - Know alternative names
 - Know how they relate to one another
- How to describe the width of the beam at each area
- Relationships between:
 - Diameter and divergence
 - Frequency and divergence
 - Diameter and focal depth
 - Frequency and focal depth

Section 9.1 Sound Beam Regions



9.1.1 Near Zone

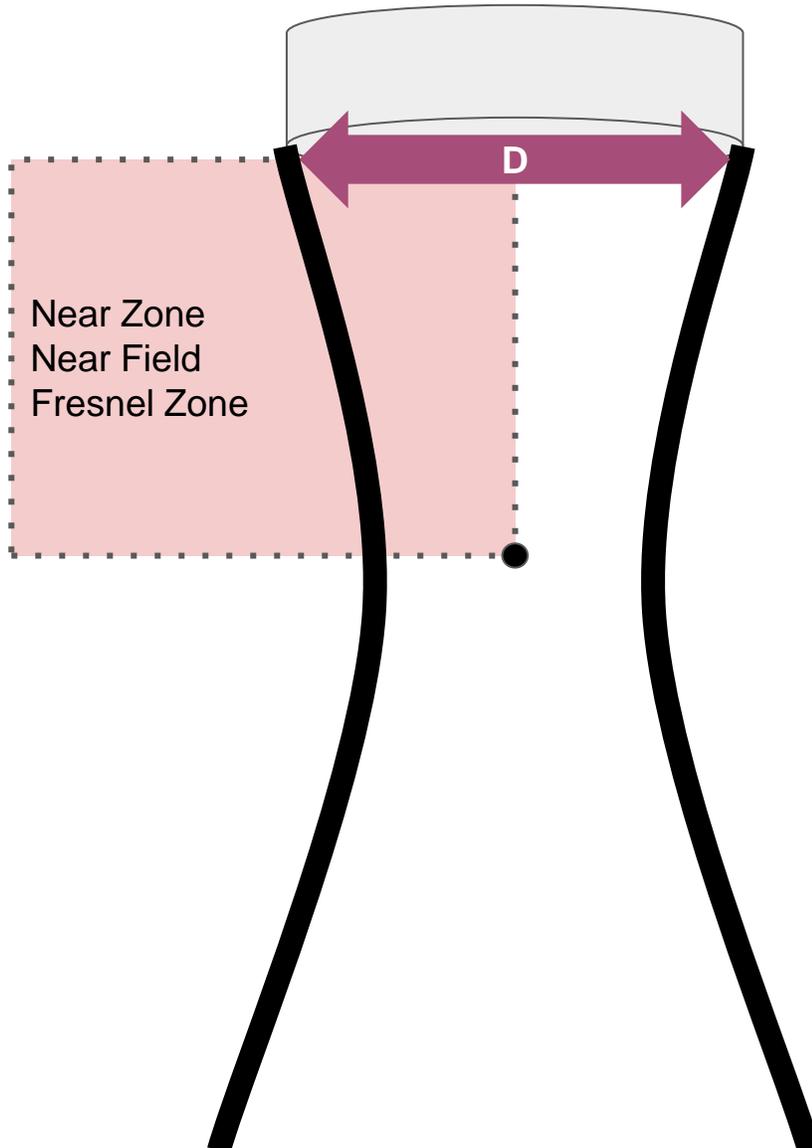
The near zone has 3 names to know:

- Near zone
- Near Field
- Fresnel Zone

When the beam leaves the transducer, it is as wide as the diameter of the transducer.

The beam will naturally narrow to its narrowest point called the focus.

- **The near field is the area between the transducer and the focus.**
- **The widest the near field will ever get is equal to the diameter of the element. The diameter of the crystal is also known as aperture. (D)**



9.1.2 Near Zone Length

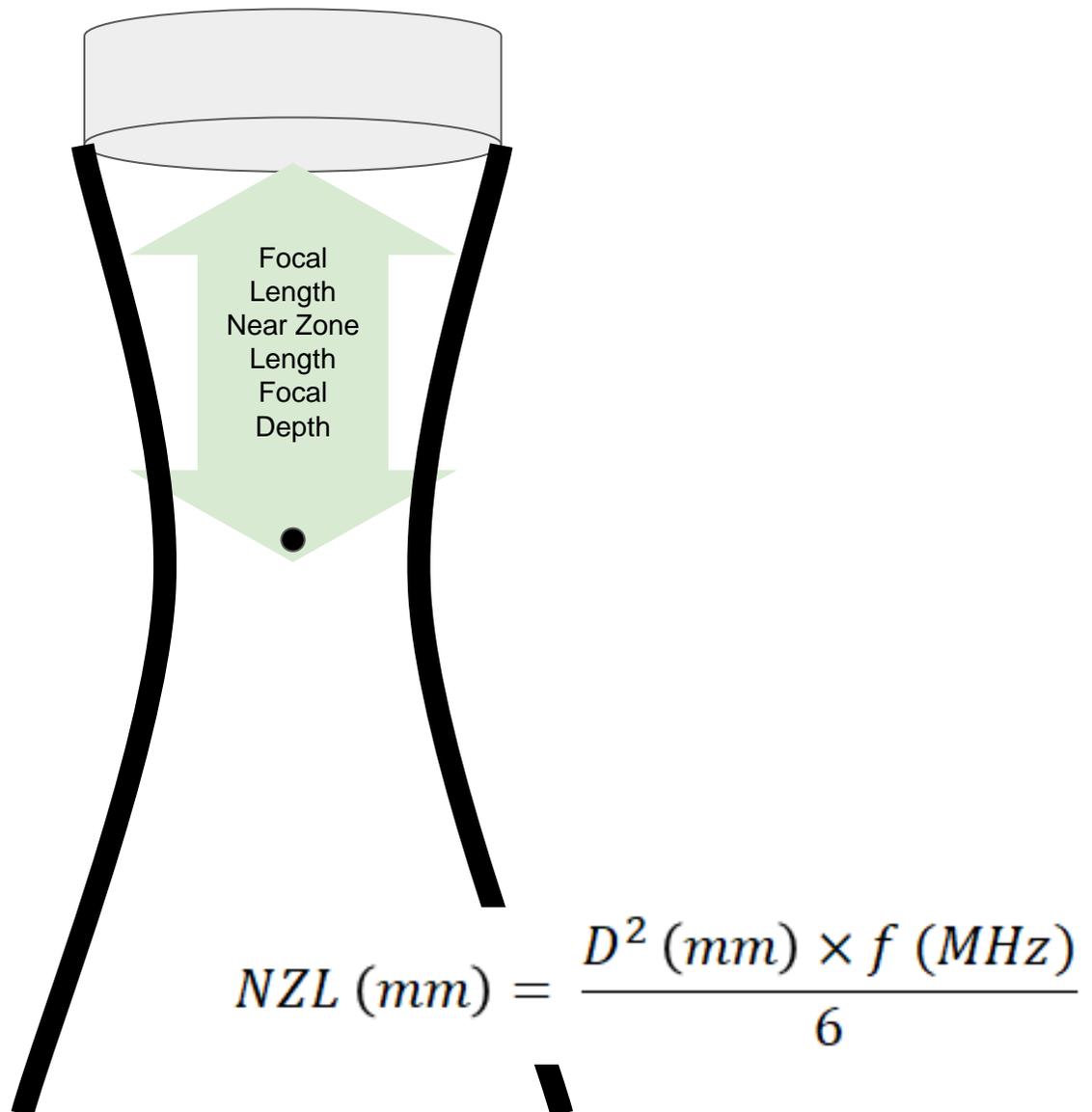
The Focal Length has 3 names to know:

- Focal Length
- Near Zone Length (NZL)
- Focal Depth

The near zone is the area of the beam from the transducer to the focus. The NZL is the amount of space the near zone takes up and can be measured in any distance unit.

The beam will naturally narrow to its narrowest point called the focus.

- **The NZL is based on frequency and transducer diameter (D)**
- **If either diameter OR frequency increase, the NZL will be deeper**



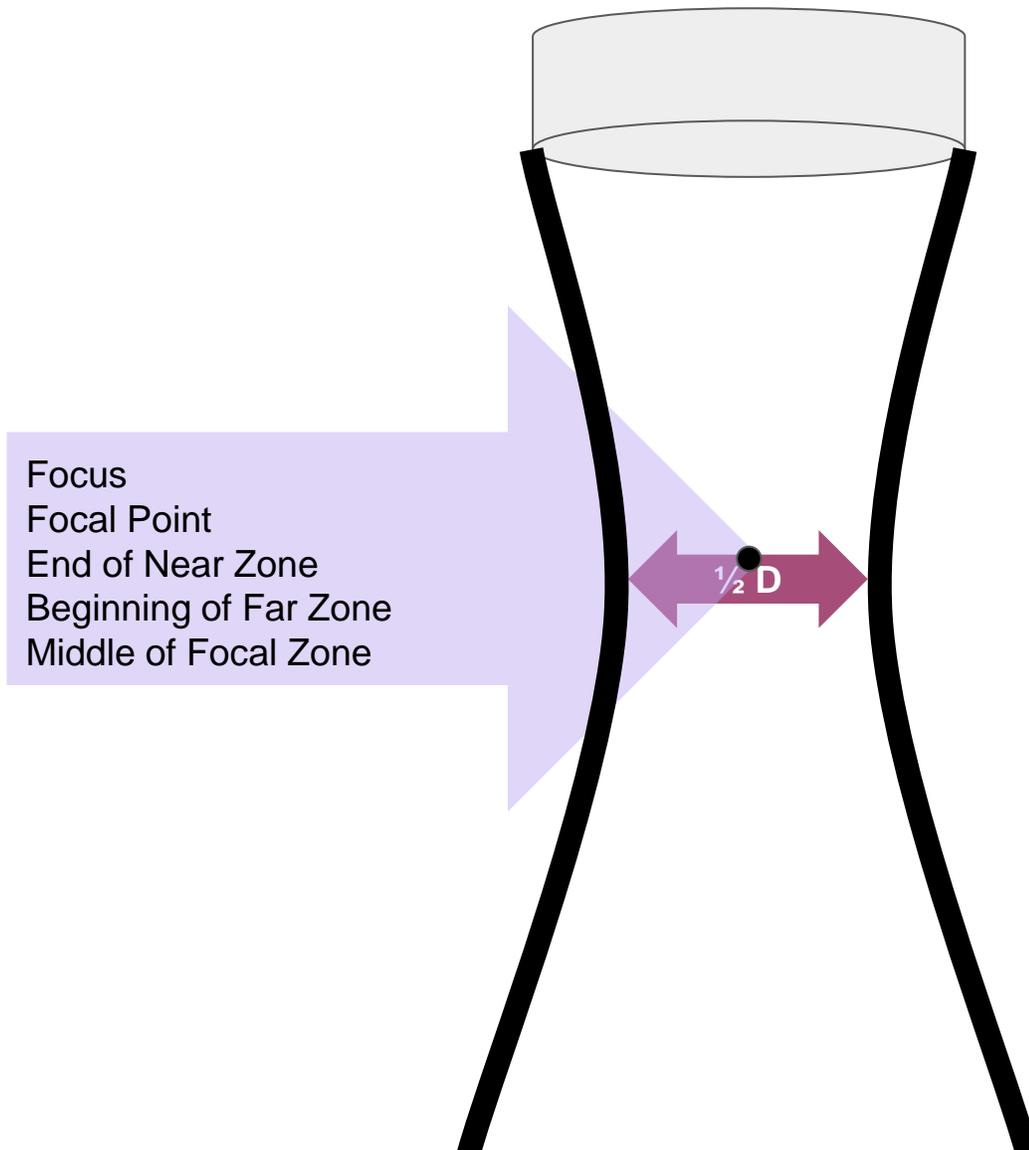
9.1.3 Focus

The focus is also known as the focal point, but we can describe it 3 more ways:

- End of the near zone
- Beginning of the far zone
- Middle of the focal zone

In the continuous wave, single element transducer, the beam will naturally focus. The focus is where the beam is narrowest and equals $\frac{1}{2}$ of the diameter of the element.

- **The focus is where the beam is narrowest**
- **Focus = $\frac{1}{2} D$**



9.1.4 Far Zone

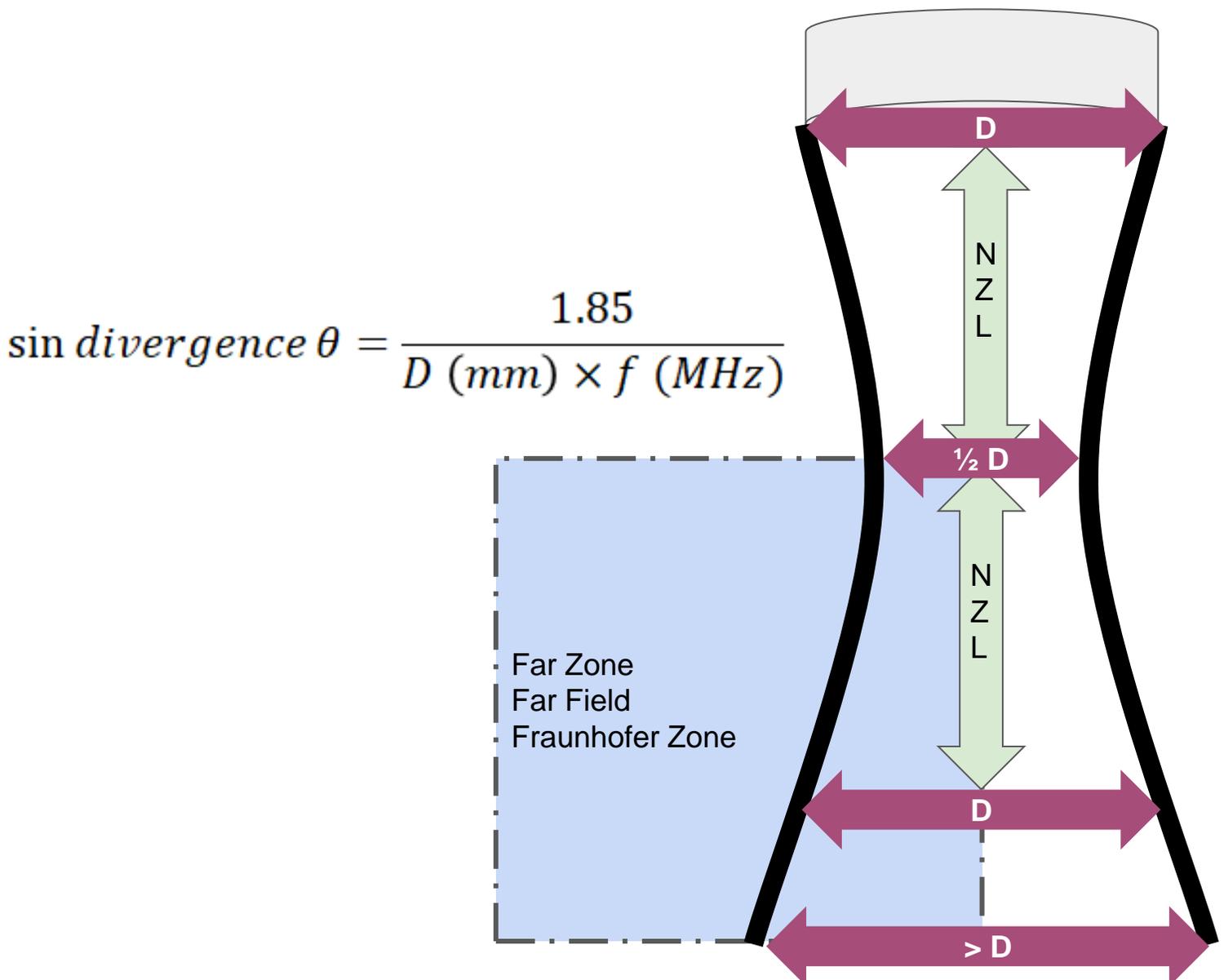
The Far Zone has 3 names to know:

- Far Zone
- Far Field
- Fraunhofer Zone

The far zone starts at the focus, where the beam is narrowest ($\frac{1}{2}$ of D) and extends for the rest of the beam.

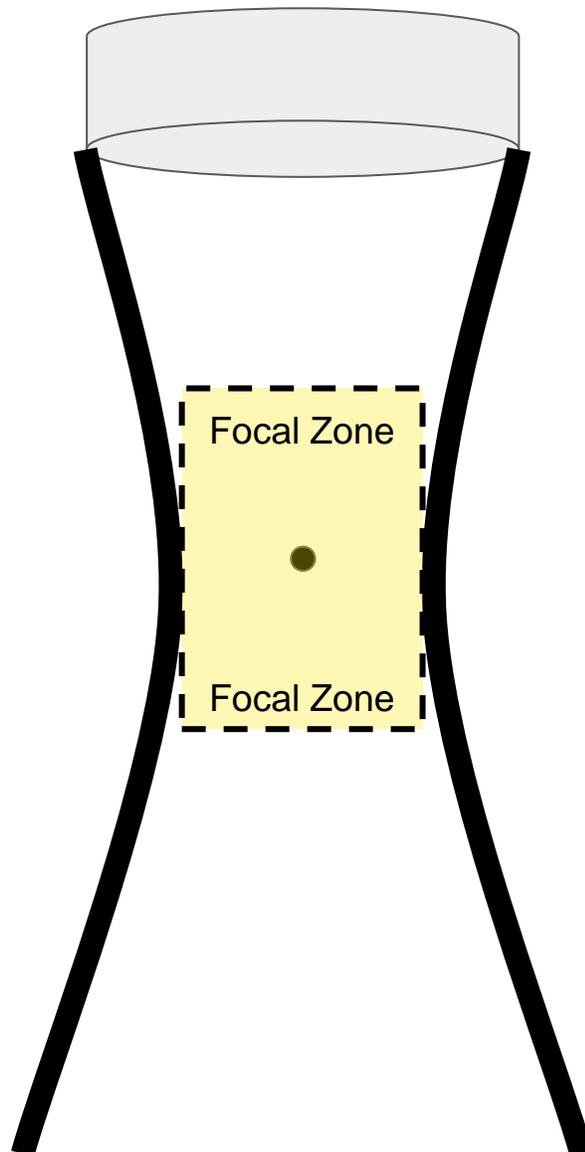
In the far zone, the beam starts to widen. It will achieve the element diameter once it reaches 2 NZLs and then continue to diverge beyond this point.

- **At 2 NZL, the far field diameter = the element diameter**
- **The amount of divergence after 2 NZL depends on transducer diameter and transducer frequency**



9.1.5 Focal Zone

The focal zone in the area of the beam that is relatively narrow. The focus is at its center and it extends equally into the near zone and the far zone. This is where the intensity of the beam is most consistent and the beam is mostly narrow. The focal zone typically offers the best image detail.



9.1 Practice

A beam is created by a 12 MHz transducer that has an 8 mm wide element.

Answer the following:

What is the width of the beam as it exits the transducer?

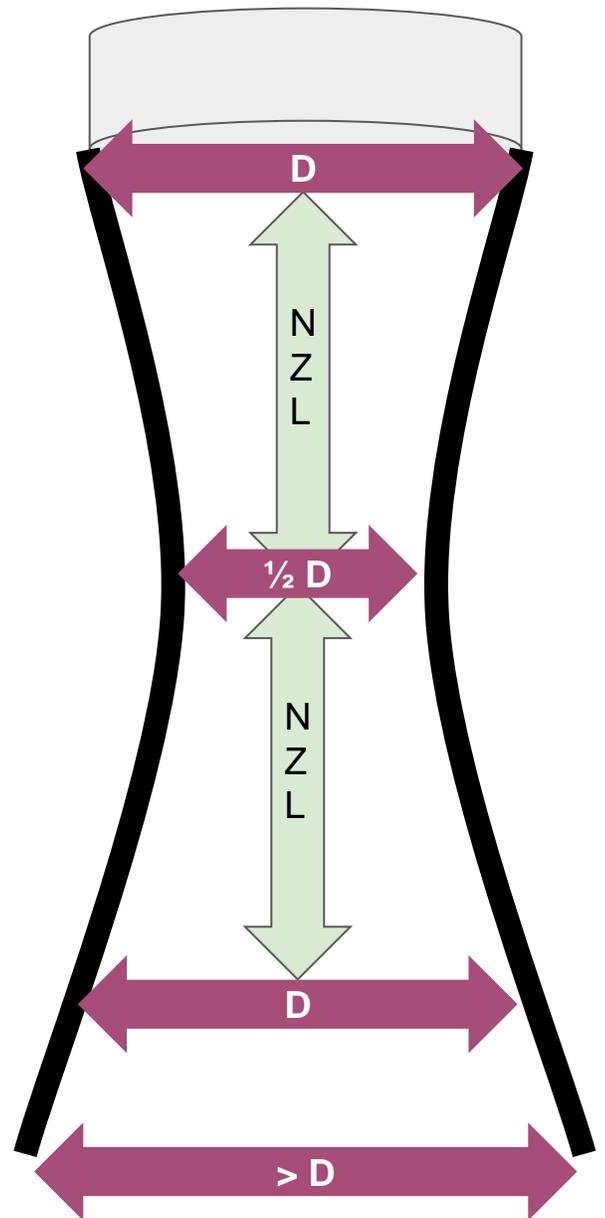
At what depth is the focus?

How wide is the beam at the focus?

At what depth in the far field does the beam diameter equal the 8 mm?

If the focal zone starts at 9.8 cm into the beam, where does it end?

What diameter is the beam at 30 cm?



$$NZL (mm) = \frac{D^2 (mm) \times f (MHz)}{6}$$

9.1 Practice

A beam is created by a 6 MHz transducer that has an 8 mm wide element.

Answer the following:

What is the width of the beam as it exits the transducer?

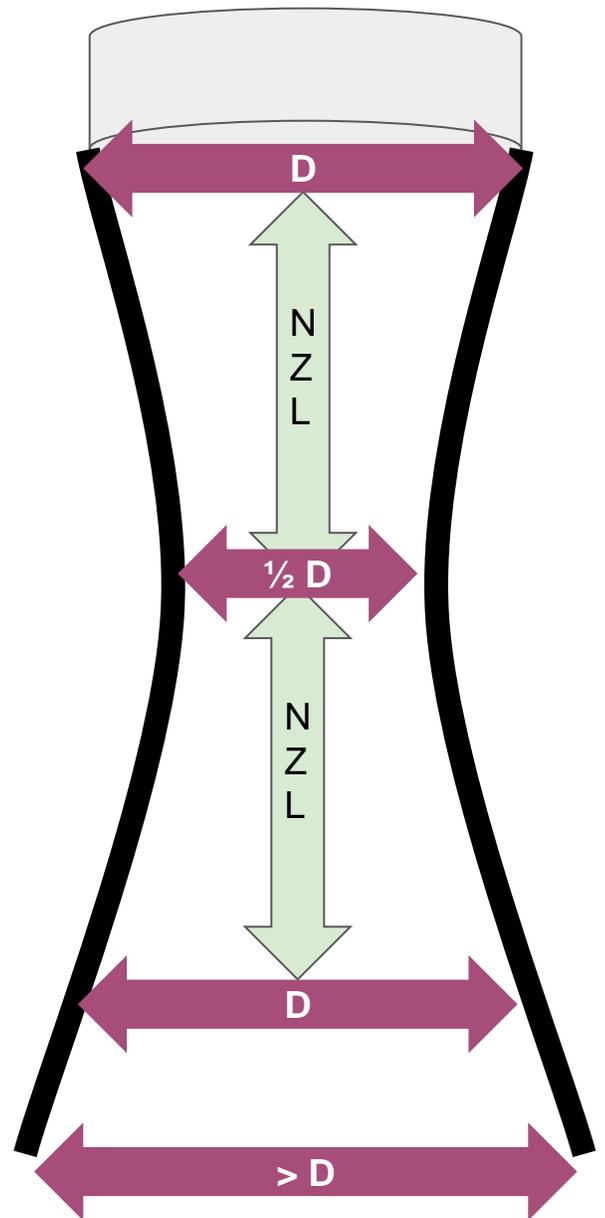
At what depth is the focus?

How wide is the beam at the focus?

At what depth in the far field does the beam diameter equal the 8 mm?

If the focal zone starts at 3.4 cm into the beam, where does it end?

What diameter is the beam at 15 cm?



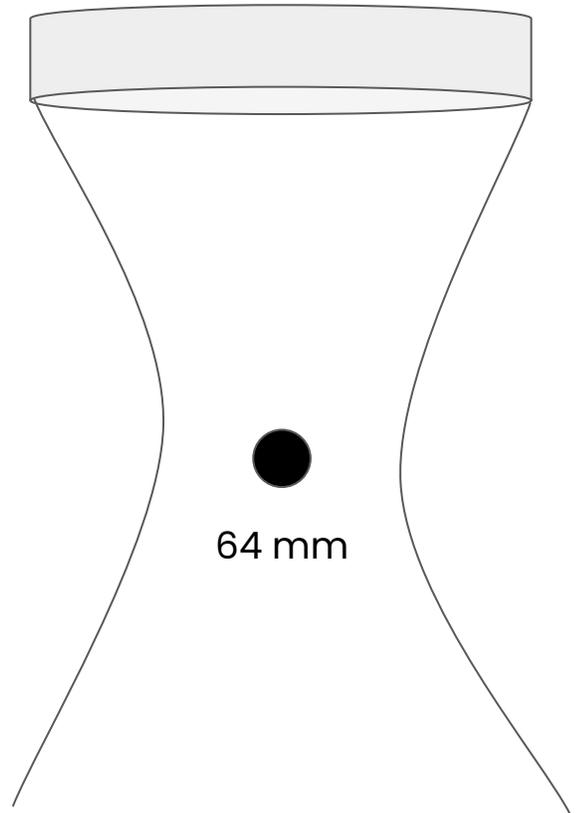
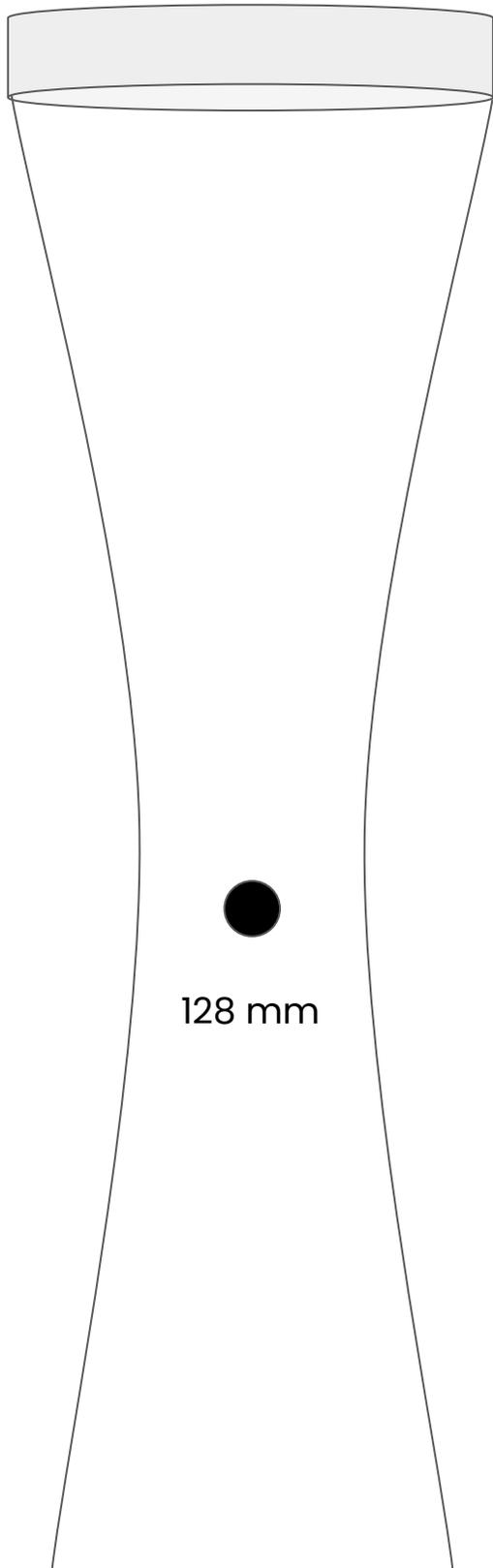
$$NZL (mm) = \frac{D^2 (mm) \times f (MHz)}{6}$$

Section 9.2 Focal Depth

In the 9.1 practice example we were given 2 transducers:

12 MHz & 8 mm diameter

6 MHz & 8 mm diameter



$$NZL (mm) = \frac{D^2 (mm) \times f (MHz)}{6}$$

Given the practice example, we were able to calculate the focal depths and see that

→ **Frequency and focal depth are directly related.**

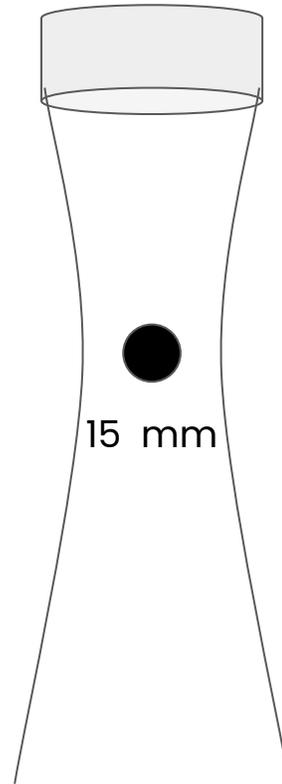
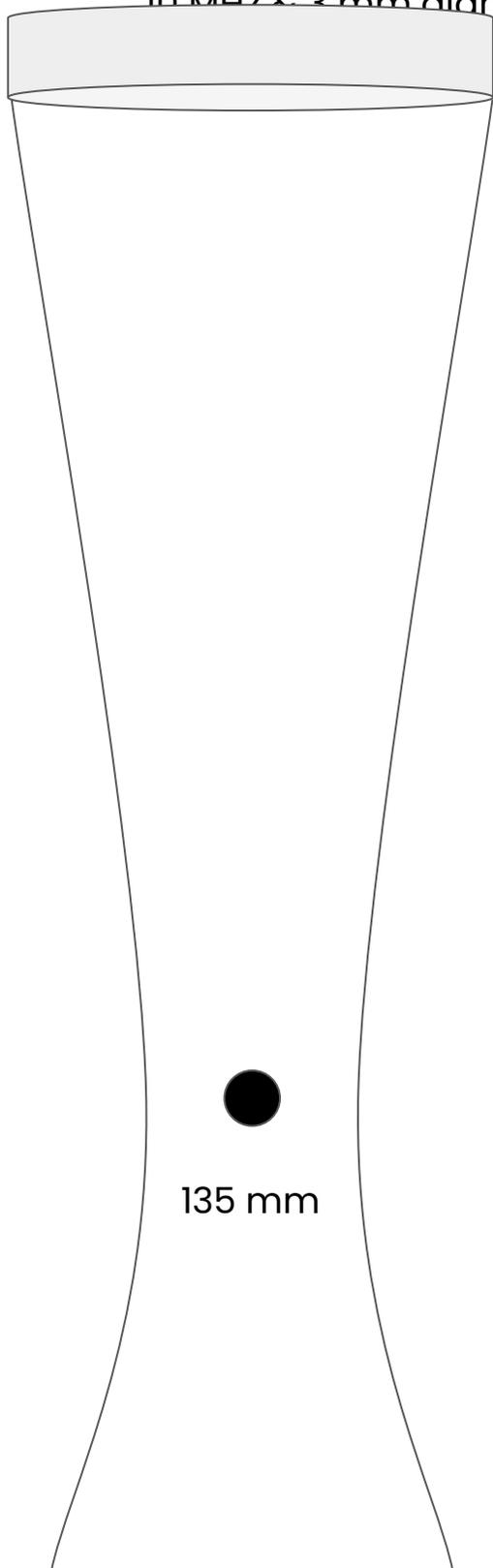
In other words: if frequency gets higher, focal depth gets deeper. If frequency gets lower, focal depth gets shallower

Looking at our formula though, we can see that crystal diameter is also a factor in determining the focal depth.

Let's change it up a bit and try out a:

10 MHz & 9 mm diameter

10 MHz & 3 mm diameter



$$NZL (mm) = \frac{D^2 (mm) \times f (MHz)}{6}$$

With these transducers we can see that

→ **Diameter and focal depth are directly related.**

In other words, if diameter gets wider, focal depth gets deeper. If diameter gets smaller, focal depth gets shallower

Section 9.3 Beam Divergence

In section 9.1.3, we learned about the far zone and that it will diverge or get wider.

The narrowest portion is where it starts and that is $\frac{1}{2}$ the diameter of the element. At 2 NZLs from the transducer it widens to the diameter of the crystal and then from here, it keeps diverging.

There is a formula that helps to describe the amount of widening:

$$\sin \text{divergence } \theta = \frac{1.85}{D \text{ (mm)} \times f \text{ (MHz)}}$$

You will not need to calculate the beam divergence ever, but rather recognize that:

- **Diameter and divergence are inversely related**
- **Frequency and divergence are inversely related**

This is important because of **lateral resolution**. Lateral resolution will be discussed in much more detail in the next unit, but lateral resolution is dependent on the width of the beam.

This is why:

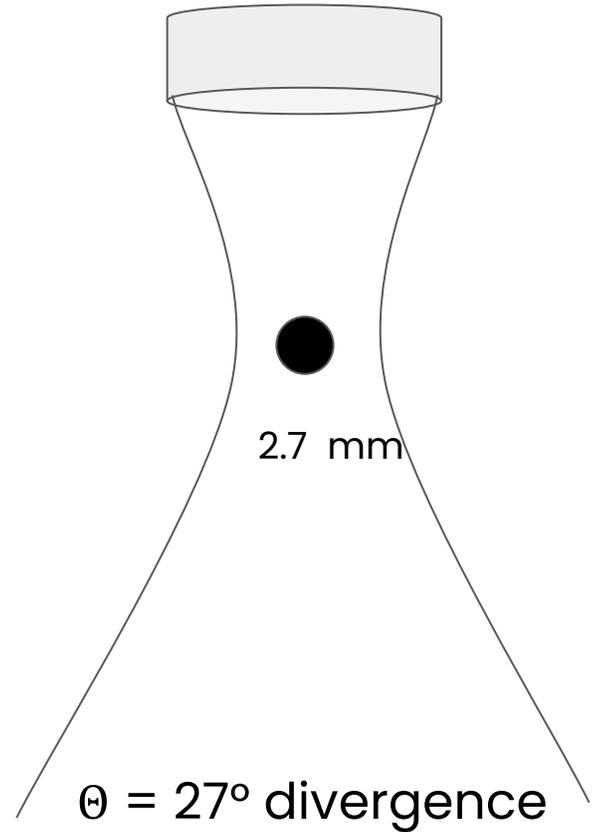
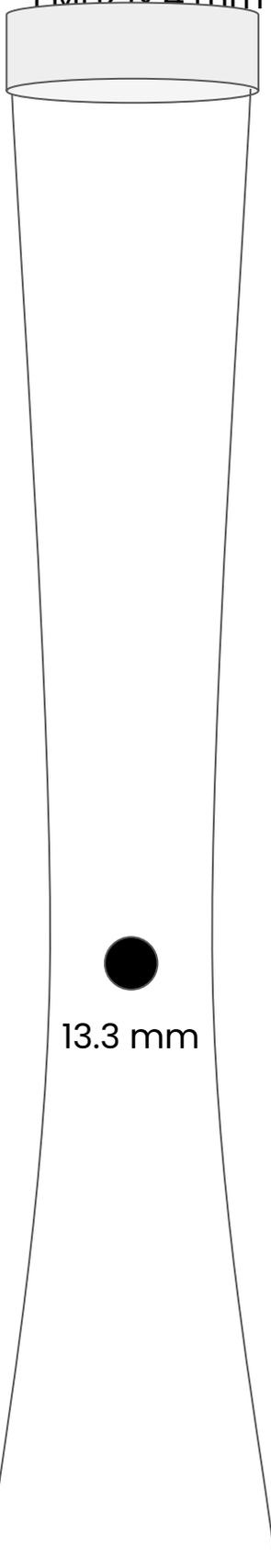
- **Focus / focal zone should be placed at area of interest or just below**
 - ◆ **Narrowest portion of the beam will provide superior detail**

- **Diverging far fields produce poor image detail. The beam is too wide to recognize small structures.**

Let's test out the new formula and some different transducer. Remember you won't have to calculate this, but rather recognize the relationships. :

5 MHz & 4 mm diameter

1 MHz & 4 mm diameter



$$\sin \text{divergence } \theta = \frac{1.85}{D \text{ (mm)} \times f \text{ (MHz)}}$$

With these transducers we can see that
→ **Frequency and beam divergence are inversely related.**

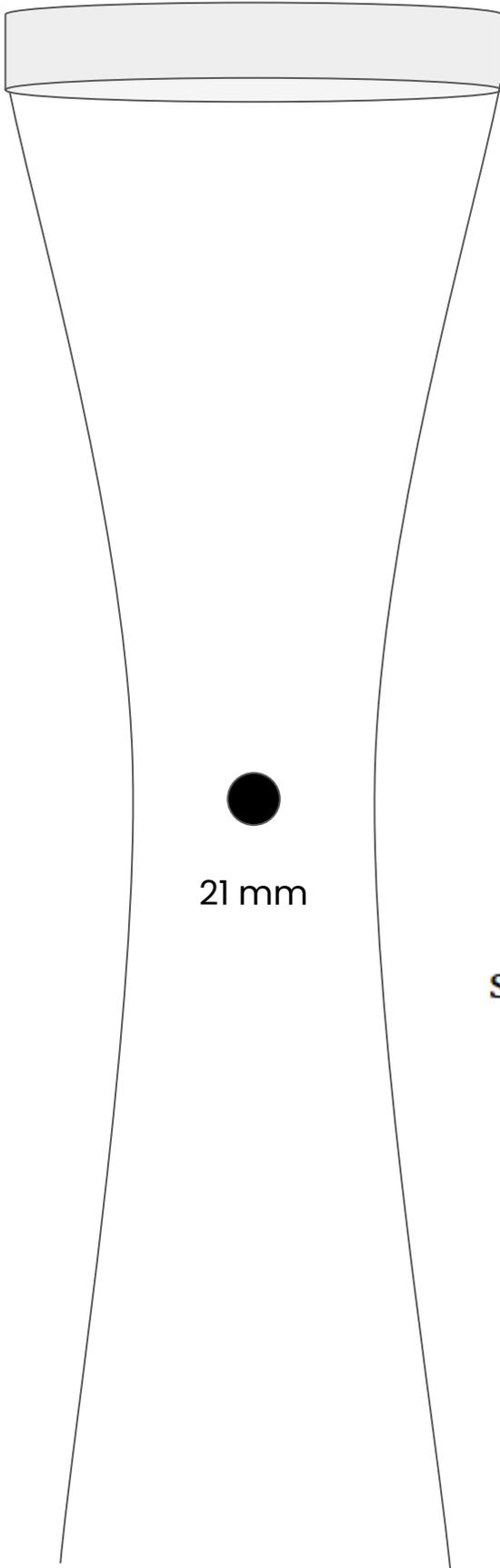
In other words, frequency gets higher, there is less divergence. If frequency gets lower, there is more divergence.

$\theta = 5^\circ$ divergence

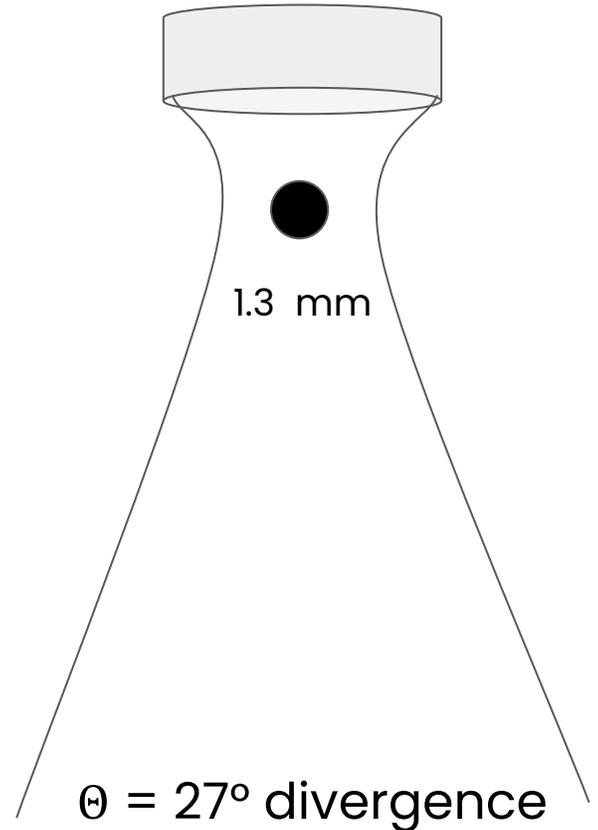
Let's try out a new set, changing the diameter between the two.

2 MHz & 8 mm diameter

2 MHz & 2 mm diameter



$\theta = 6^\circ$ divergence



$$\sin \text{divergence } \theta = \frac{1.85}{D \text{ (mm)} \times f \text{ (MHz)}}$$

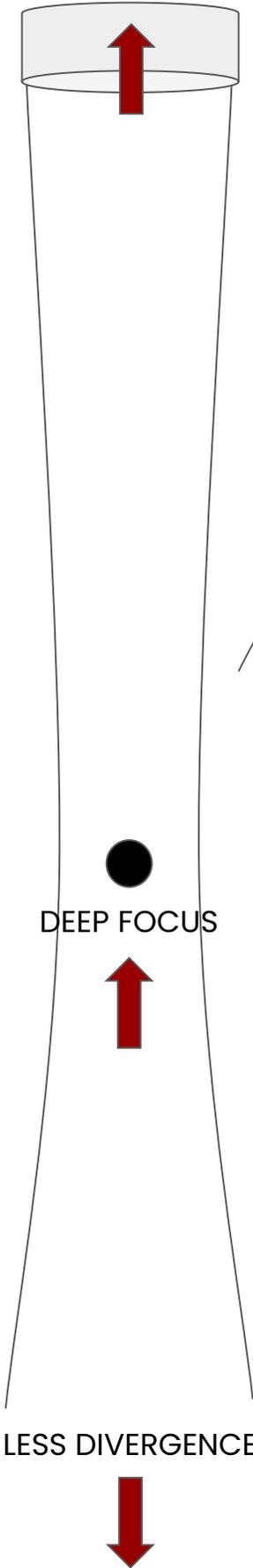
With these transducers we can see that

→ **Beam diameter and beam divergence are inversely related.**

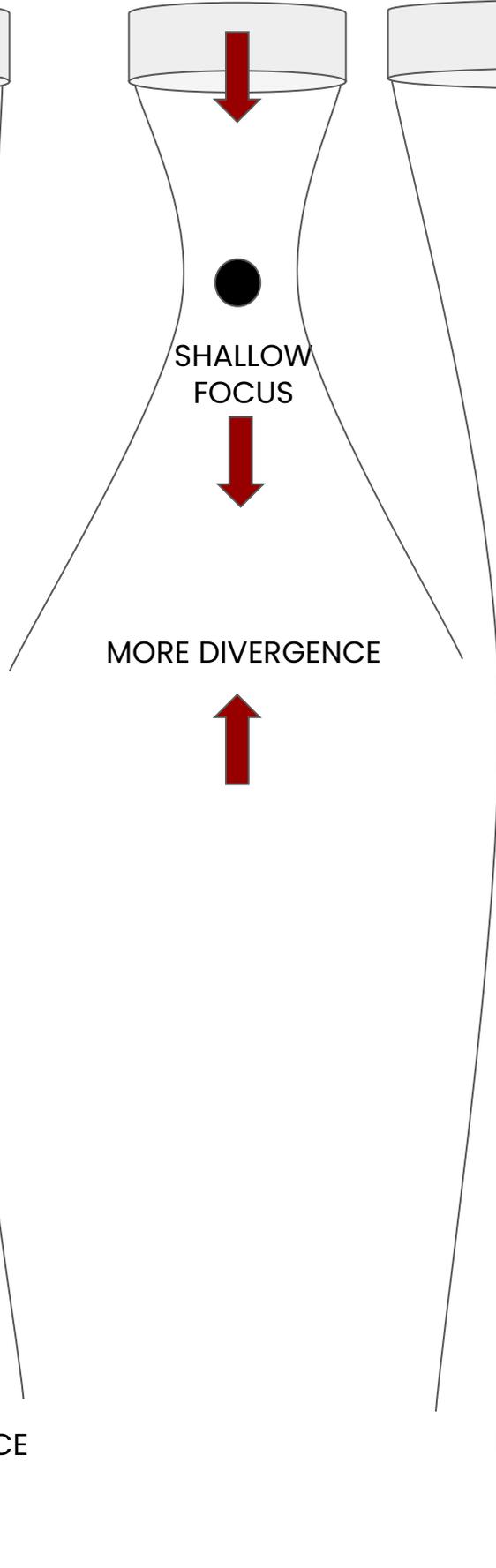
In other words, as the diameter gets wider, less divergence occurs. If the diameter gets small, more divergence occurs.

Section 9.4 Review

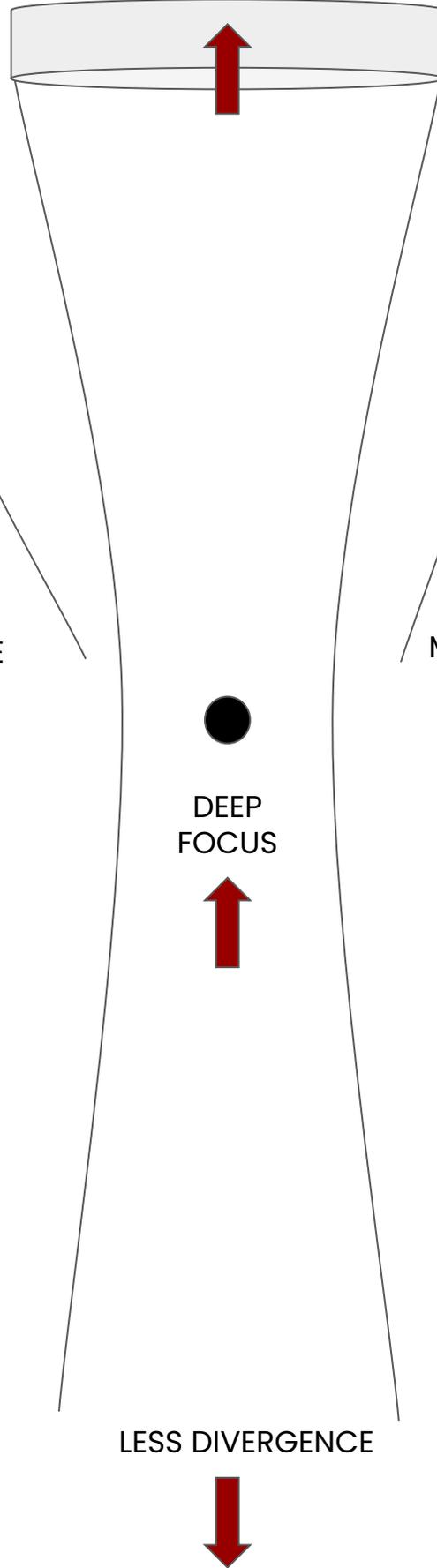
HIGH FREQUENCY



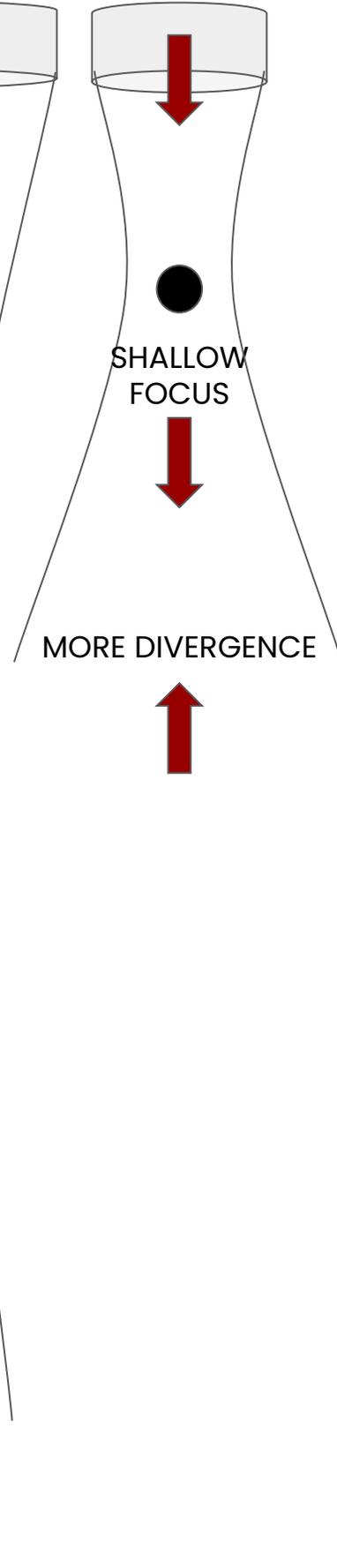
LOW FREQUENCY



WIDE DIAMETER



SMALL DIAMETER



IF YOU CAN REMEMBER...

DIAMETER & FREQUENCY DETERMINE

N_{ZL}

NUMERATOR

DIRECTLY RELATED TO QUOTIENT

$$N_{ZL} (mm) = \frac{D^2 (mm) \times f (MHz)}{6}$$

D

DIVERGENCE

DENOMINATOR

$$\sin \text{divergence } \theta = \frac{1.85}{D (mm) \times f (MHz)}$$

INVERSELY RELATED TO QUOTIENT

9.4 Practice

Which transducer will have a **deeper** focus?

10 mm diameter	OR	19 mm diameter
12 MHz	OR	5 MHz

Which transducer will have a **shallower** focal point?

27 mm aperture	OR	13 mm aperture
1 MHz	OR	4 MHz

Which transducer beam will diverge **more**?

6 mm diameter	OR	3 mm diameter
7 MHz	OR	2 MHz

Which transducer beam will diverge **less**?

23 mm diameter	OR	33 mm diameter
10 MHz	OR	17 MHz

Which transducer will have the best lateral resolution in the Fraunhofer zone?

10 MHz, 4 mm diameter

12 MHz, 10 mm diameter

1 MHz, 3 mm diameter

5 MHz, 8 mm diameter

Section 9.5 Clinical Discussion

We needed to over simplify the beam shape to discuss some of the key features of the beam and learn how it acts in space. For modern, clinical ultrasound, the physics is more complex.

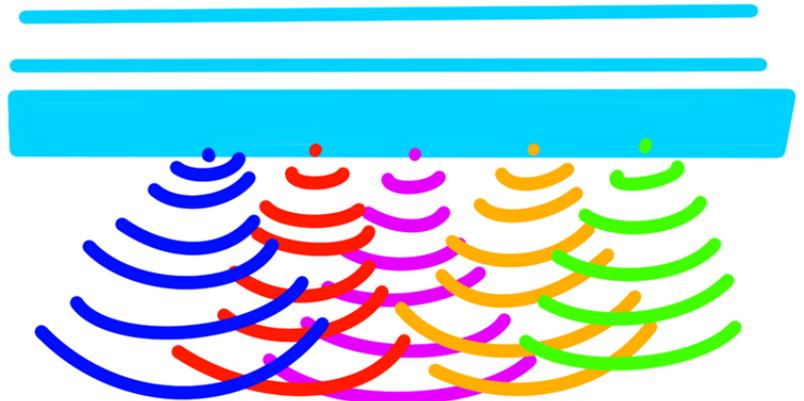
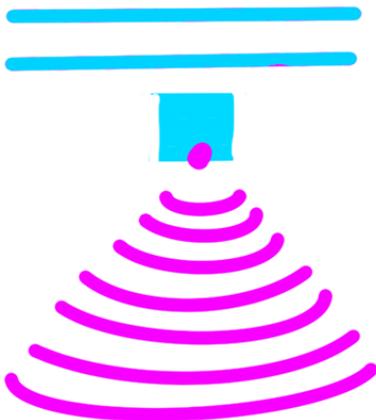
I have a focus knob on my machine, is that the focus we've been talking about?

No. The beams in this unit have all been "unfocused," meaning they don't have anything that is causing them to focus like a lens, curved element or electronic focusing patterns (spoiler - we're going to learn about all of these soon!). These beams do have a *natural focus* though and that is because of:

- **Diffraction**
- **Huygen's Principle**

When the PZT crystal is created, they can be made very small or they can be made a little bigger, but still have small sound producing points. The sound wave that comes out of a small PZT area takes on a **V-shaped wave, also known as a Huygens' Wavelet**. The small v shaped wave is created because of diffraction.

Huygens' principle tells us that when many little wavelets interact, they will interfere with one another - both constructively and destructively. The result is a natural focus, or the hourglass shape we have been discussing.



If high frequency transducers have a deep focal depth AND less divergence, why are they only used for superficial imaging?

The physics tells us that the higher the frequency, the deeper the focal point and the less divergence that will occur. It is easy to think that if we're imaging only a few centimeters into the body that the focal point should be shallow too.

The physics also tells us that high frequency transducers are going to attenuate really quickly - usually before we can get meaningful information from their deep focal points.

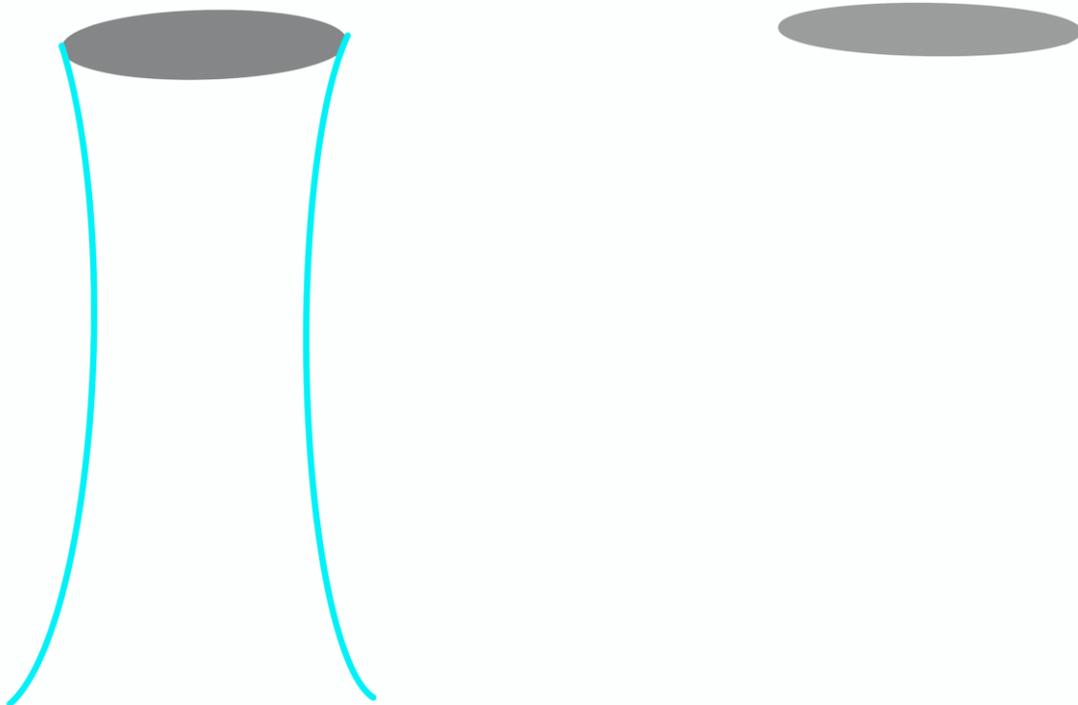
BUT the physics also tells us that small diameter crystals will cause the focus to be shallow. Knowing this, many high frequency transducers are going to be made with very small crystals to bring the focus to a more useful depth.

17 MHz transducer with a 8 mm aperture would have a focal depth of 18 cm.

A 17 MHz transducer with a 1 mm aperture has 2.8 cm focal depth.

If these are all continuous waves, what does a pulsed wave look like?

Basically the same, however, the sound beam isn't always present to the same depths at all times. The sound wave needs to propagate through the length of the beam to create the shape.



Is the intensity the same all the way through the beam?

The drawings that we used to show the beam shape show the beam narrowing at a natural focus. This makes sense that this is the strongest part of the beam because the power of the sound converges to a smaller area (Remember the Intensity formula? $I = P/\text{Area}^2$)

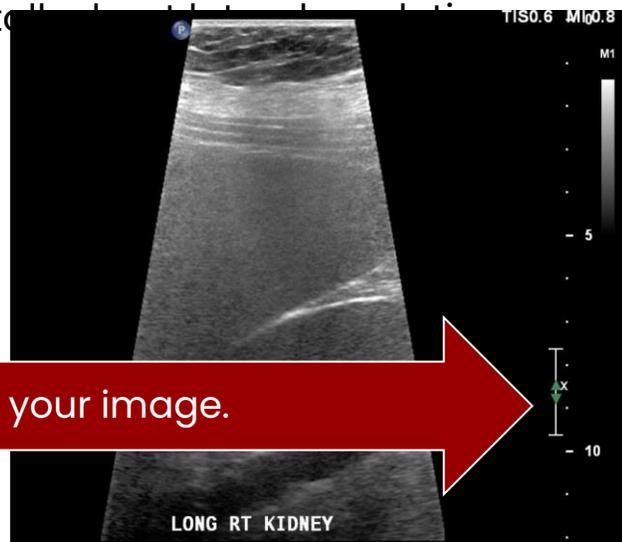
While this is essentially true in the clinical setting, the beams we have been using do not account for attenuation. In reality, the beam is weakening because of attenuation as it propagates, so it is losing power as it travels to the focal point.

This makes the area just before the focus the real “more intense” area of the beam. The beam has narrowed AND has attenuated too much.

This is clinically significant because our modern machines allow us to change where the focus is located. **Therefore, the focus should be placed at or just below the area of interest or the bottom of your desired anatomy.**

→ **The stronger part of the beam AND the narrowing beam will provide the best image.**

We will touch more on this when we talk about focusing.



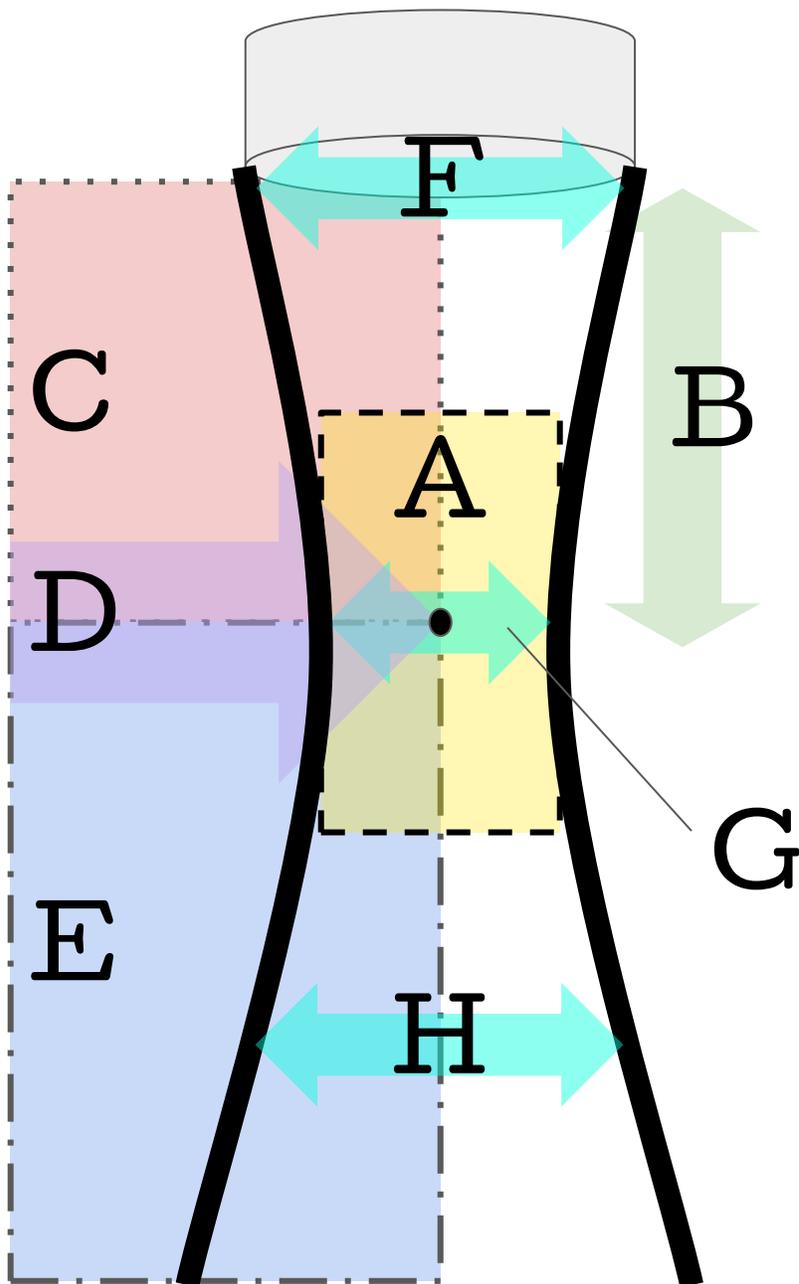
Move the focus to optimize your image.

Does the ultrasound beam create the whole image?

No. One pulsed beam will create one scan line. Many scan lines create a full frame (image). When we learn about transducers we'll learn how the PZT crystals work together to create a beam/scan line.

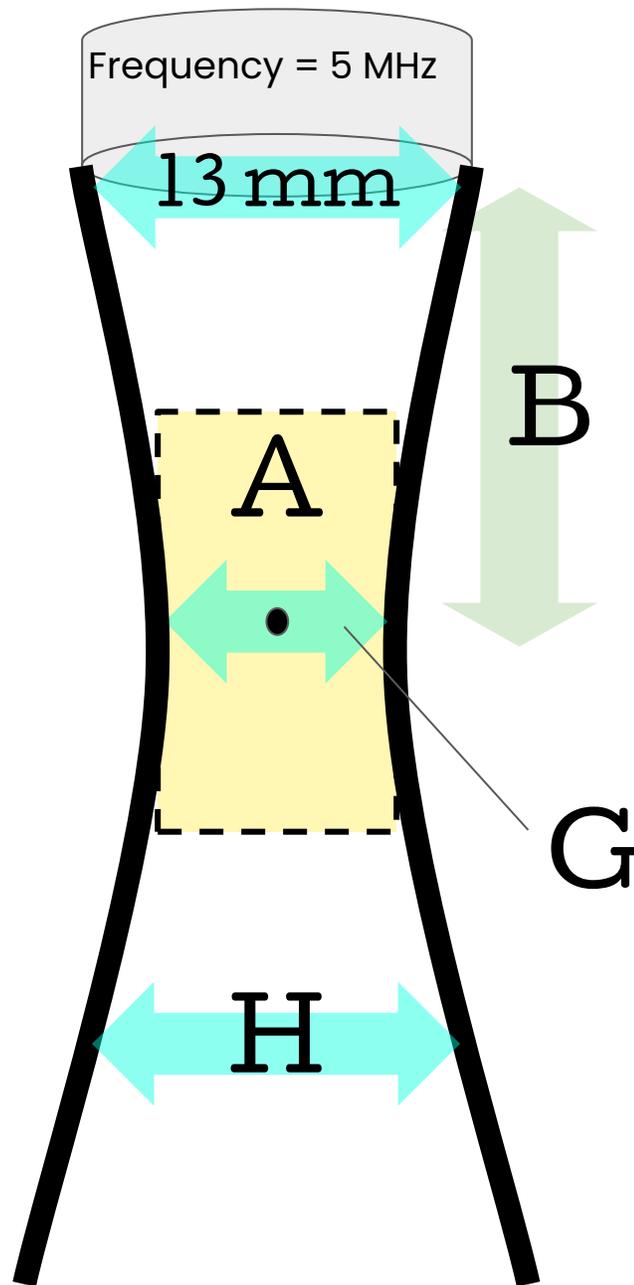
Section 9.6 Activities ← [Link to Answers](#)

1. Use the image to match the letters to the area described. More than one letter may be correct.



	Near Zone
	Far Zone
	Same diameter as crystal
	NZL
	Focal Depth
	$\frac{1}{2}$ crystal diameter
	Area of convergence
	Focus
	End of the Fresnel Zone
	Focal Zone
	Focal Point
	Near Field
	Directly related to frequency & diameter
	Area of divergence
	Provides the best lateral resolution
	Focal Length
	Fraunhofer Zone
	Middle of the focal zone
	Aperture of crystal
	Beyond this point the width is inversely related to frequency and diameter

2. Calculate the following and fill in the chart.



What is the beam diameter at arrow G?	
What is the beam diameter at arrow H?	
What is the length of arrow B?	
Area A is 4 cm long, at what depth does it start? *	
What depth does Area A end?	

* The focal zone is equidistant into the near zone and far zone. The focus is in the middle.

3. How does focal depth & beam divergence relate to frequency and diameter?
Drag the pieces to the correct spot.

Low Frequency

High Frequency

Narrow Aperture

Wide Aperture

**Less
Divergence**

**More
Divergence**

**Shallow
Focal Point**

**Deep Focal
Point**

4. Fill in the blanks.

is the physical principle behind the creation of V-shaped waves from small sound sources.

The constructive and destructive interference of waves to create a naturally focused beam is

To counteract the deep focal depth created by high frequency PZT crystals, the crystal are very in diameter.

The best place to put the focal point/ focal zone in an image is at or just below the are of interest because this is where the intensity is and the beam

One pulse creates one sound beam. One sound beam creates one

Section 9.7 Nerd Check!

1. What does converge mean?
2. What does diverge mean?
3. Describe where the near zone is.
4. What are other names for the near zone?
5. How wide is the near zone when it leaves the transducer?
6. When does the near zone end?
7. What is another name for diameter?
8. Describe what the Near Zone length is.
9. What are other names for the NZL?
10. How is the NZL calculated?
11. Describe the far zone.
12. What are other names for the far zone?
13. When does the far zone start?
14. When does the far zone end?
15. What happens in the far zone to the beam width?
16. When will the far zone diameter equal the transducer diameter?
17. What is the smallest the far zone will be?
18. What is the focus?
19. Describe 3 other ways the focal point is related to the other zones.
20. What size is the beam at the focus?
21. What is the focal zone?
22. How is the focal zone related to the focus?
23. How far does the focal zone go into the near zone and far zone?
24. How are frequency and focal depth related?
25. How are diameter and focal depth related?
26. How are frequency and beam divergence related?
27. How are diameter and beam divergence related?
28. How is the hourglass shape of the beam created?
29. How do we make high frequency transducers better at shallow imaging?
30. Where is the strongest part of a non-attenuating beam?
31. Where is the strongest part of a beam being used to create ultrasound images?
32. How does the beam relate to image creation?