



**ARDMS Topic:
Ultrasound Transducers**

**Unit 8:
Transducer Anatomy**

**Sononerds Ultrasound Physics
Workbook & Lectures**

Unit 8: Transducer Anatomy

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Unit 8: Transducer Anatomy

[Entire Unit 8 Lecture:](#)

Sononerds
in the classroom



Unit 8: Transducer Anatomy

Unit 8: Transducer Anatomy

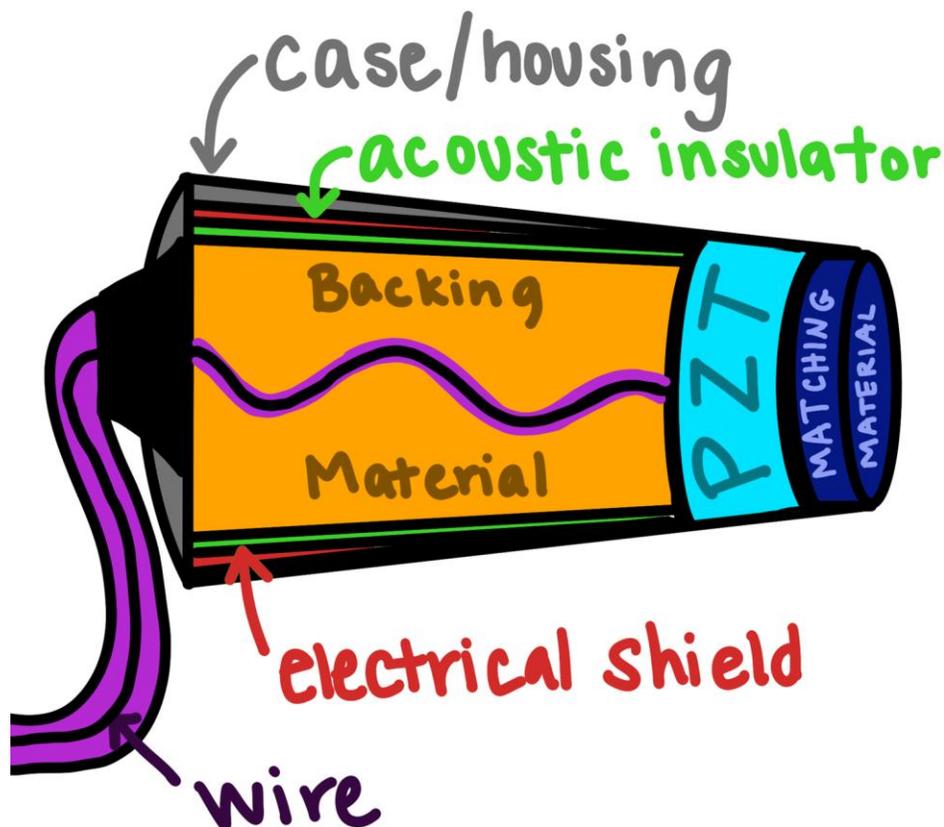
→ **A transducer is any device that changes one form of energy into another.**

There are many types of transducers in everyday life. For example:

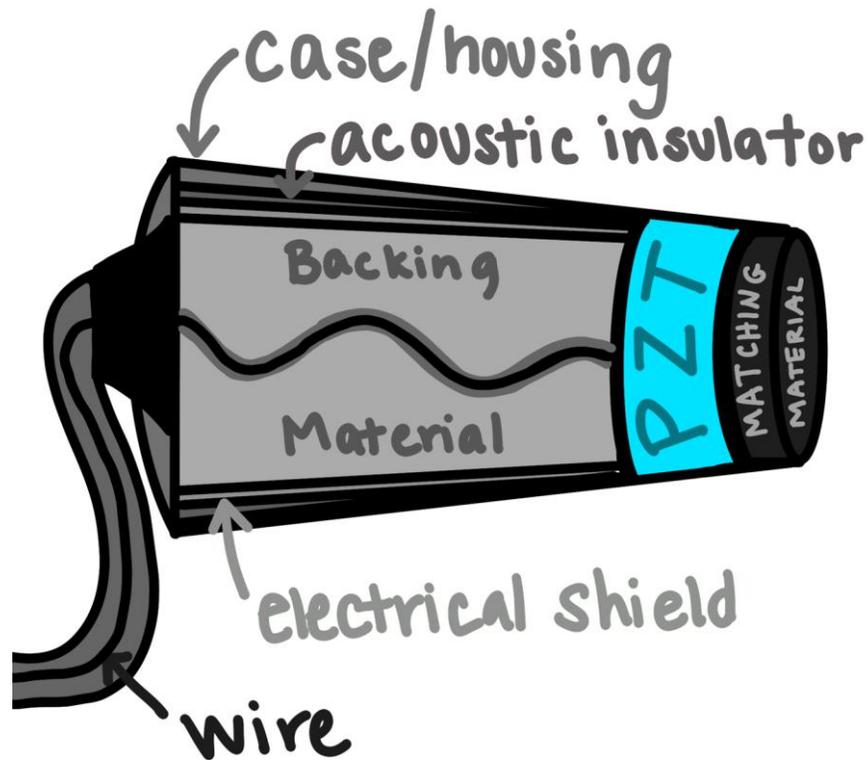
- An engine takes gas or chemical energy and converts it into kinetic or motion energy.
- Light bulbs take electrical energy and convert the energy into light and some heat.
- Our bodies can even act like transducers. The muscles can take chemical energy and change it into motion.

The transducers that are part of an ultrasound system are special transducers. They are considered bi-directional. The previous examples show energy conversion that can only happen in one direction.

Here is a drawing of a basic transducer. To better understand the very complex transducers used with modern ultrasound systems, we can begin by deconstructing a simple, single element transducer. In a single element transducer, the PZT is disc shaped. We are going to learn more about each piece in the next sections.



Section 8.1 PZT Element



The ultrasound transducer is capable of changing electrical energy into sound AND sound energy into electrical. The part of the transducer that is responsible for the bi-directional conversion is called the piezoelectric element.

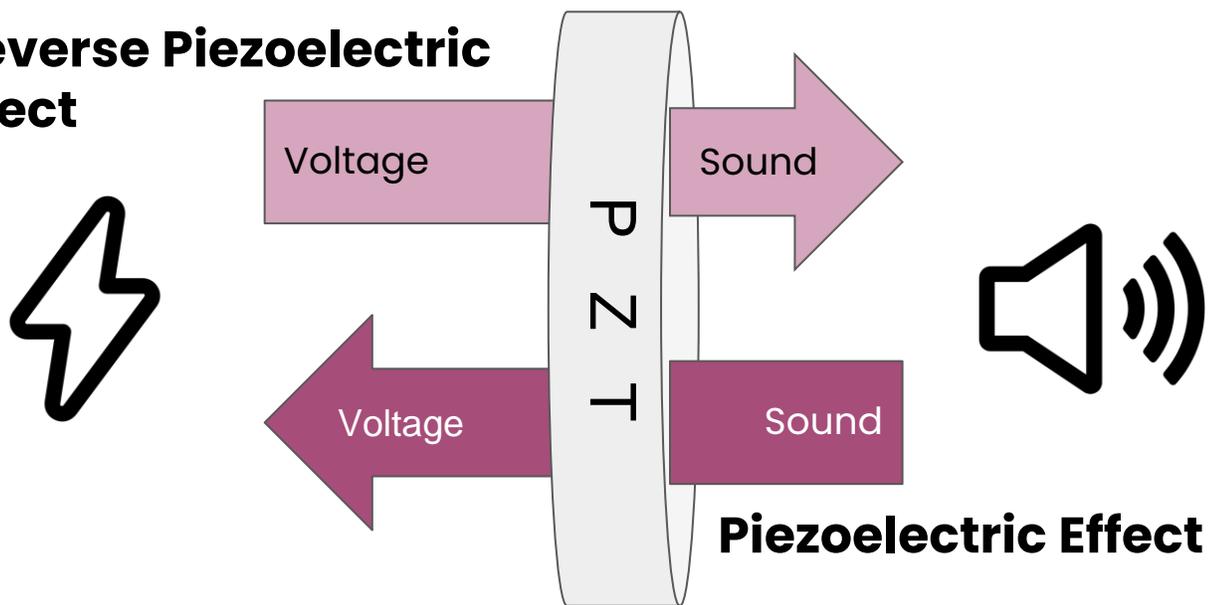
→ **The act of turning sound (pressure waves) into electrical volts is called the piezoelectric effect.**

The piezoelectric effect occurs during **reception**, when echoes are coming back from the body.

→ **The act of turning electrical volts into sound waves is called the reverse piezoelectric effect.**

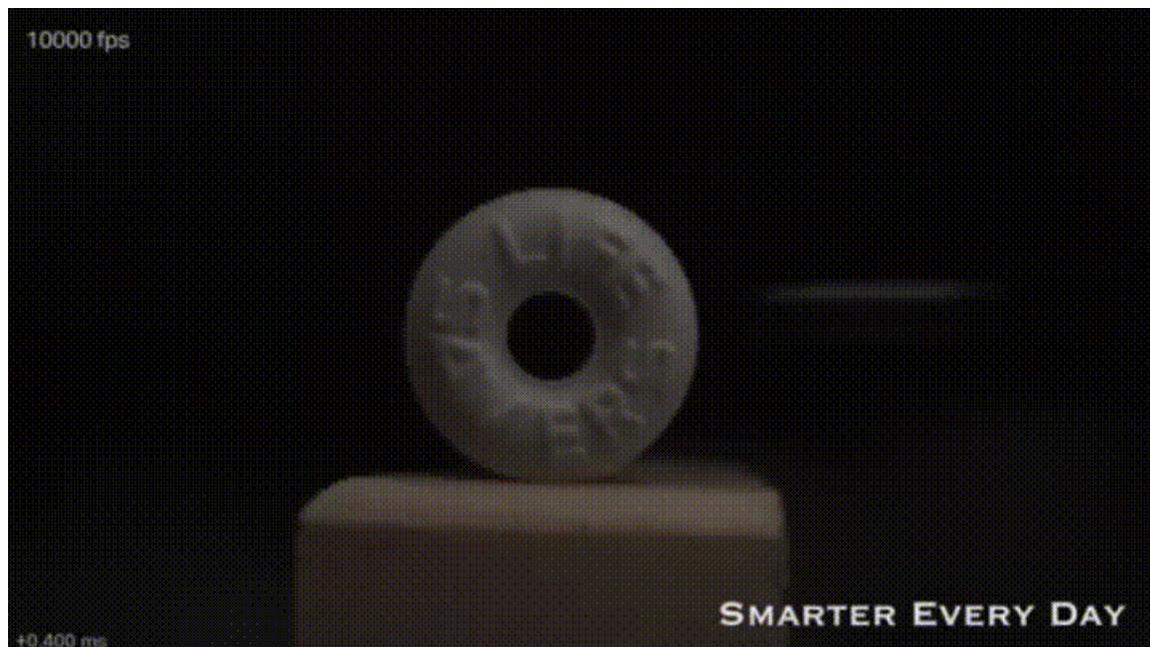
The reverse piezoelectric effect occurs during **transmission** when the transducer is emitting sound waves into the body.

Reverse Piezoelectric Effect



During transmission, the piezoelectric material will change shape when a voltage is applied. The shape change will cause a sound wave to be produced. In the ultrasound system, it is the machine that sends a voltage to the transducer for conversion to an ultrasound wave. This is the reverse piezoelectric effect.

During reception, the piezoelectric element will again change shape when the sound pressure is applied. The shape change produces an electrical voltage. This is the piezoelectric effect. Recall that sound is a mechanical or pressure wave. When sound is coming back from the body, it interacts with the piezoelectric material to produce a voltage. That voltage is sent to the machine to be processed and turned into the ultrasound image.

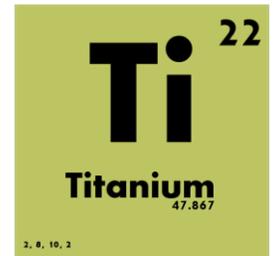
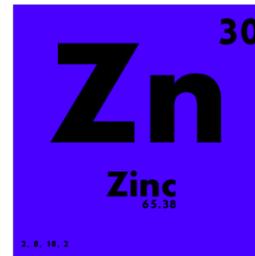
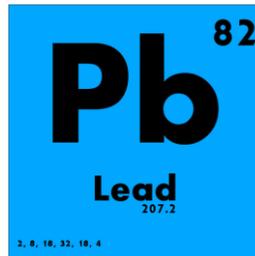


8.1.1 PZT Element Creation

Piezoelectric material can be found in nature. Some examples of piezoelectric material also known as ferroelectric material include quartz, topaz, cane sugar and tourmaline.



However, natural sources are more likely to have imperfections. Therefore, ultrasound manufacturers are more likely to create their own piezoelectric material. The most commonly man made material used is **lead zirconate titanate or PZT**.



Why PZT? The Z and the T may be obvious, but the P is derived from the table of elements in which lead is abbreviated by Pb, which is short for the Latin term plumbum.

Manmade materials have some pitfalls.

Manmade materials are not naturally piezoelectric. To make the PZT piezoelectric, it is subjected to very high heat while in a magnetic field.

The downfall then is that if the transducer is subjected to high levels of heat after construction, the material will lose its piezoelectric properties. This high temperature is called the Curie Point. Thankfully, the Curie point is extremely high over 500 degrees fahrenheit or about 300 degrees celsius. The odds of encountering these extreme temperatures is very low.

Another pitfall of the manmade PZT material is that it has a high impedance. Compared to the low impedance of the skin, the large mismatch means less of the sound will enter the body.

To combat this, the PZT material is mixed with a resin into a composite. The piezo-composite is made just right to improve the element's bandwidth, sensitivity and resolution.

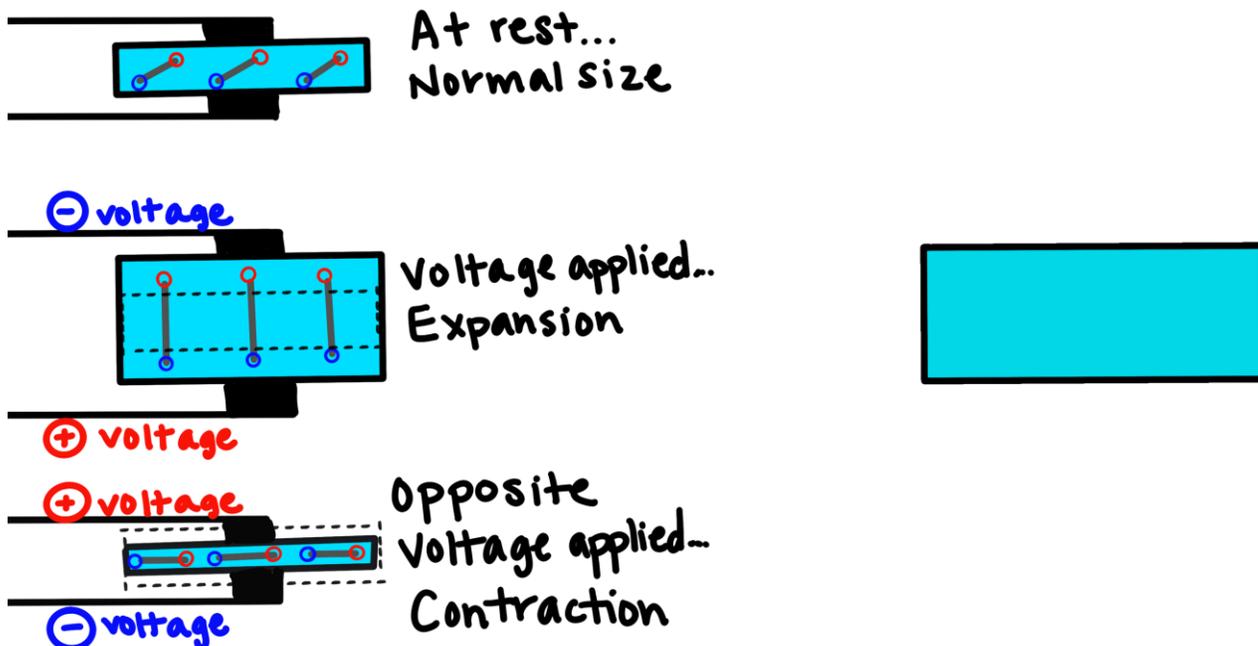
Whatever the piezoelectric material is made of, it is commonly referred to as the

→ **PZT, ceramic, active element or crystal.**

Section 8.1.2 Creating the Frequency

- **At least one element is needed to create a 2D image**, however modern transducers have 100's of crystals at the face.
- **Continuous wave transducers need at least 2 elements.**

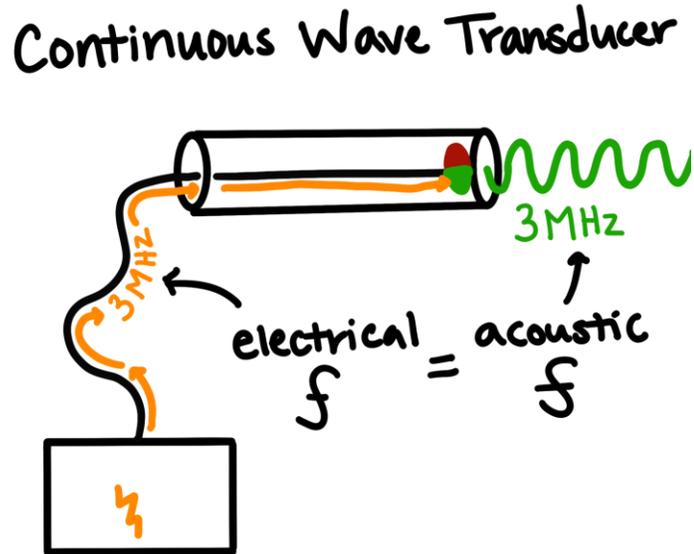
Each crystal connects to a wire, that connects back to the machine. When voltages come down the wire they will cause the PZT crystal to resonate - or change shape. The contraction and expansion of the material creates the sound wave.



In a **continuous wave transducer**, the voltage that comes down the wire is the frequency of the wave the crystal produces.

The wave is always being transmitted and received. Remember CW transducers do not produce images.

electrical frequency = acoustic frequency



In **pulsed wave transducers**, the sound is pulsed, meaning it has an on and off time. During those pulses multiple PZT elements are activated. The waves they create are very small wavelets (Huygen's Waves). The wavelets will construct and destruct, creating the propagating pulse.

In **pulsed wave transducers** the frequency at which the PZT resonates at is based on 2 things:

- **Thickness**
- **Propagation speed**

The formula for Operating Frequency as it relates to the PZT element is:

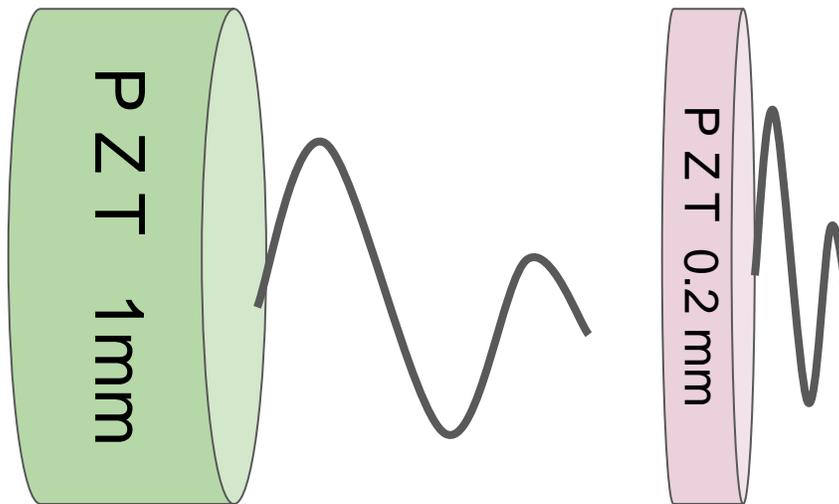
$$frequency_{operating} (MHZ) = \frac{c_{PZT} \left(\frac{mm}{\mu s} \right)}{2 \times Thickness_{PZT} (mm)}$$

- **Most PZT material has a propagation speed of about 4 -6 mm/ μ s and elements usually range from about 0.2 mm to 1 mm thick.**

Based on the frequency formula related to the PZT thickness, the relationships to know are:

→ **Frequency and element thickness are inversely related.**

- ◆ **Thicker elements create lower frequencies.**
- ◆ **Thinner elements create higher frequencies.**



Using our formula:

Let's use:

4 mm/ μ s propagation speed

1 mm PZT Thickness

$$2 \text{ MHz} = \frac{4 \text{ mm}/\mu\text{s}}{2 \times 1 \text{ mm}}$$

Now let's try:

4 mm/ μ s propagation speed

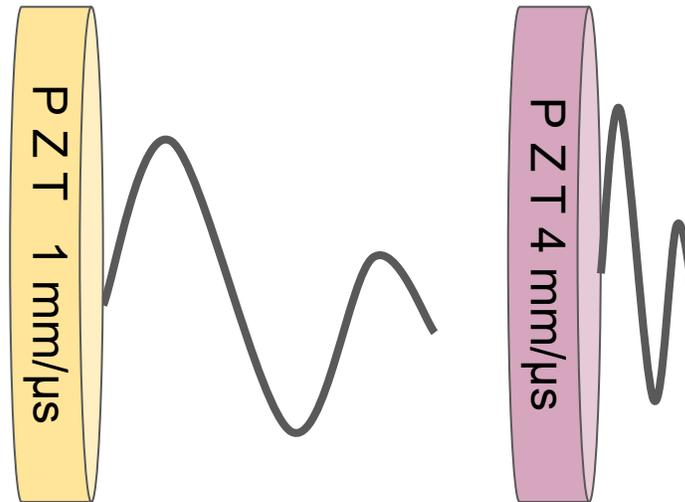
0.2 mm PZT Thickness

$$10 \text{ MHz} = \frac{4 \text{ mm}/\mu\text{s}}{2 \times 0.2 \text{ mm}}$$

We can see that as thickness increases, the frequency decreases. Making these two variables inversely related. BUT we can figure that out too knowing that the denominator is inversely related to the quotient.

Based on the frequency formula related to the propagation speed, the relationships to know are:

- **Frequency and propagation speed are directly related.**
 - ◆ **Slow propagation speeds create lower frequencies.**
 - ◆ **Fast propagation speeds create higher frequencies.**



Using our formula:

Let's use:

1 mm/μs propagation speed

0.2 mm PZT Thickness

$$2.5 \text{ MHz} = \frac{1 \text{ mm}/\mu\text{s}}{2 \times 0.2 \text{ mm}}$$

Now let's try:

4 mm/μs propagation speed

0.2 mm PZT Thickness

$$10 \text{ MHz} = \frac{4 \text{ mm}/\mu\text{s}}{2 \times 0.2 \text{ mm}}$$

We can see that as propagation speed increases, so does frequency. Making these two variables directly related. BUT we can figure that out too knowing that the numerator is directly related to the quotient.

As a derivative of the operational frequency formula and wavelength formula, the PZT being equal to $\frac{1}{2}$ the wavelength also tells us that as frequencies increases, the wavelength decreases, which means the PZT thickness also decreases. Note that we have to use the generic wavelength formula (NOT the soft tissue) because the propagation speed in the PZT material is different than soft tissue.

$$frequency_{operating} (MHZ) = \frac{c_{PZT} \left(\frac{mm}{\mu S} \right)}{2 \times Thickness_{PZT} (mm)} \qquad \lambda (mm) = \frac{c (mm/\mu S)}{f (MHZ)}$$

New Formula  $Thickness_{PZT} = \frac{1}{2} \times \lambda$

To summarize, in Pulsed Wave Transducers:

High Frequency	Low Frequency
Short Wavelengths	Long Wavelengths
Thin PZT crystals	Thick PZT crystals
Fast PZT propagation speed	Slow PZT Propagation speed

In Continuous Wave Transducers:

Electrical frequency = Acoustic Frequency

8.1.2 Practice

Transducer A has a propagation speed of $6 \text{ mm}/\mu\text{s}$ and a thickness of 0.4 mm . Transducer B has a propagation speed of $3 \text{ mm}/\mu\text{s}$ and a thickness of 0.4 mm . Based on this information, which will have the higher frequency?

Use a formula to prove it.

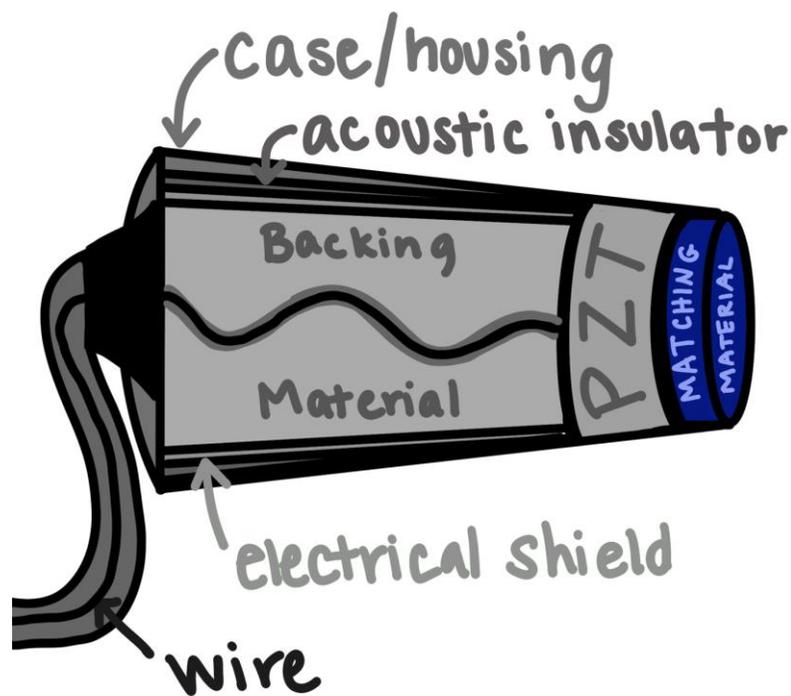
Transducer A has a propagation speed of $6 \text{ mm}/\mu\text{s}$ and a frequency of 12 MHz . Transducer B has a propagation speed of $4 \text{ mm}/\mu\text{s}$ and a frequency of 10 MHz . Based on this information, which element will be thicker?

Use a formula to prove it.

Transducer A has a propagation speed of $6 \text{ mm}/\mu\text{s}$ and a thickness of 0.3 mm . Transducer B has a propagation speed of $6 \text{ mm}/\mu\text{s}$ and a thickness of 0.8 mm . Based on this information, which will have the higher frequency?

Use a formula to prove it.

Section 8.2 Matching Layer



- **Used to direct sound into the body by being an impedance between the element and the skin. The matching layer is related to the transducer frequency.**

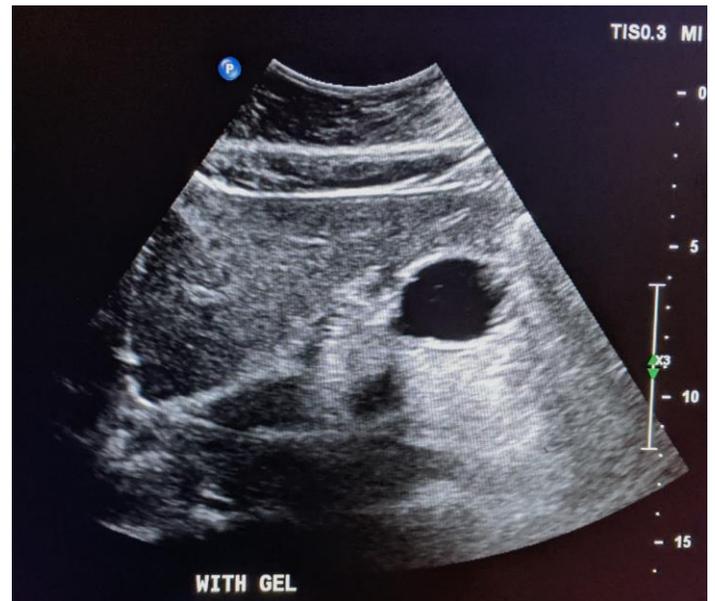
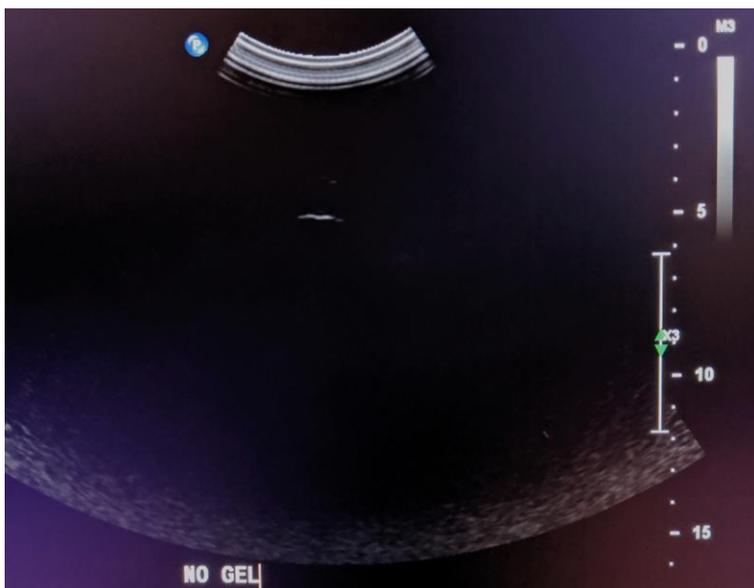
The matching layer helps sound to be transmitted into the body by being a "middle impedance" compared to the element and skin. The impedance value of the PZT is about $20 \times$ that of the skin. Recall that LARGE impedance mismatches meant more reflection occurs. The matching layer aims to reduce the mismatch.

Without the matching layer, very little sound would actually make it into the body. To provide sufficient balance to the PZT, the matching layer is $\frac{1}{4}$ the thickness of the wavelength. This means that as frequency increases, the PZT becomes thinner and the matching layer becomes thinner.

$$Thickness_{Matching\ Layer} = \frac{1}{4} \times \lambda$$

The matching layer is actually comprised of multiple layers, each layer acting as a step down in impedance to allow more sound to be transmitted, rather than reflected.

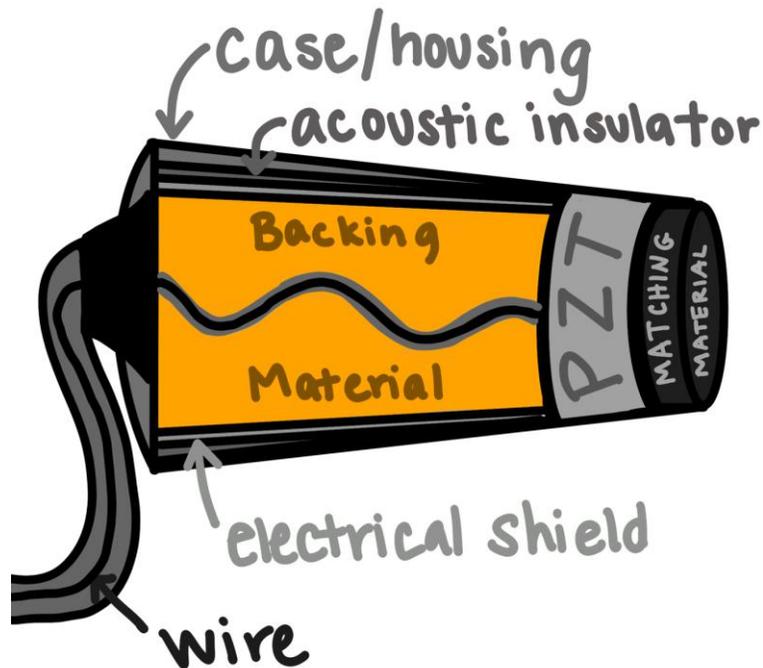
Another “must have” in ensuring sound goes into the body instead of being almost completely reflected is the gel, which is also known as the coupling medium. The gel even further reduces the impedance mismatch between the element and the skin. The gel also eliminates the scattering that even a thin layer of air would cause.



In decreasing order of impedance it is the

PZT → Matching Layer(s) → gel → skin

Section 8.3 Backing Material



- **Also known as dampening material, it is in direct contact with PZT elements. The backing material is often made of resin mixed with metallic powder or filliments. The backing material keeps the PZT material from “ringing” too long by reducing the number of cycles in each pulse**

Recall that the spatial pulse length or SPL increases with the more cycles it contains. When the PZT is allowed to ring, it will add more cycles to a pulse. Long SPLs can degrade the quality of the image, therefore backing material is added to imaging transducers to keep the pulses shorter and improve axial resolution.

Backing material should have an acoustic impedance similar to the PZT so the sound is encouraged to travel through it. The backing material should also be good at absorbing sound. Most dampening material is made of epoxy resin with tungsten filaments in it.

Backing material does have some consequences (not all bad!) though:

- **It can decrease sensitivity, meaning that it could cause the transducer to “miss” low amplitude reflectors**
- **It can cause a wide bandwidth**
- **And it can lower the Quality Factor (which is not the same as the quality of the image)**

8.3.1 Backing Material & Sensitivity

→ Backing material decreases an ultrasound system's sensitivity

Sensitivity is the machine's ability to process and display weak echoes. When sound waves come back to the transducer, they have attenuated quite a bit, so they are very weak. They still need to interact with the PZT material to create the electrical voltage that will become the image.

Dampening material shortens the PZT elements reaction time in both transmission and *reception*. Therefore, those weak echoes become even weaker due to the backing material, to the point that they might even be detectable anymore.

This means that the machine does not receive the signal, thus reducing its ability to detect and display weak echoes.

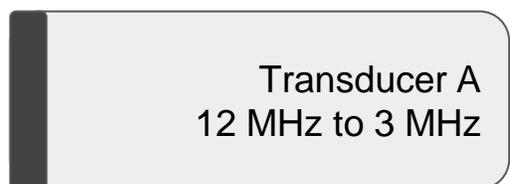
8.3.2 Backing Material & Bandwidth

→ Backing material increases the transducer bandwidth

Bandwidth is the range of useful frequencies that a device can operate at. Many imaging transducers can operate at multiple frequencies. The bandwidth is the highest frequency, minus the lowest frequency.

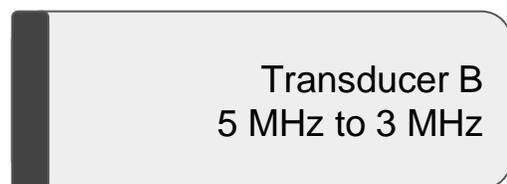
$$\text{bandwidth} = \text{frequency}_{\text{maximum}} - \text{frequency}_{\text{minimum}}$$

A wide bandwidth has a higher bandwidth numerical value, where a narrow bandwidth has a low bandwidth numerical value. The center of the bandwidth is the resonant frequency or operating frequency.



12 - 3 = 9 MHz Bandwidth (WIDE)
(NARROW)

Resonant Frequency = 7.5 MHz
MHz



5 - 3 = 2 MHz Bandwidth

Resonant Frequency = 4

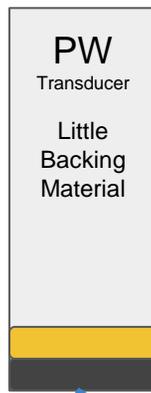


CW transducer with no backing material will “ring” at a pure frequency.

There will a lot (infinite) cycles.

This creates a very narrow bandwidth

Since the spatial pulse length doesn't exist, this type of transducer cannot create images.



A PW transducer with just a little backing material will create a pulse with many cycles.

This has a wider bandwidth than a CW transducer, but a narrower bandwidth than a transducer with more backing material.

This transducer will have poor detail resolution because of the long pulses.

But, will be more sensitive to weak returning echoes.



A PW transducer with a lot of backing material will basically create a “click.” The click will have very few cycles and contain multiple frequencies.

The multiple frequencies creates a wider bandwidth.

The short SPL will create superior detail resolution.

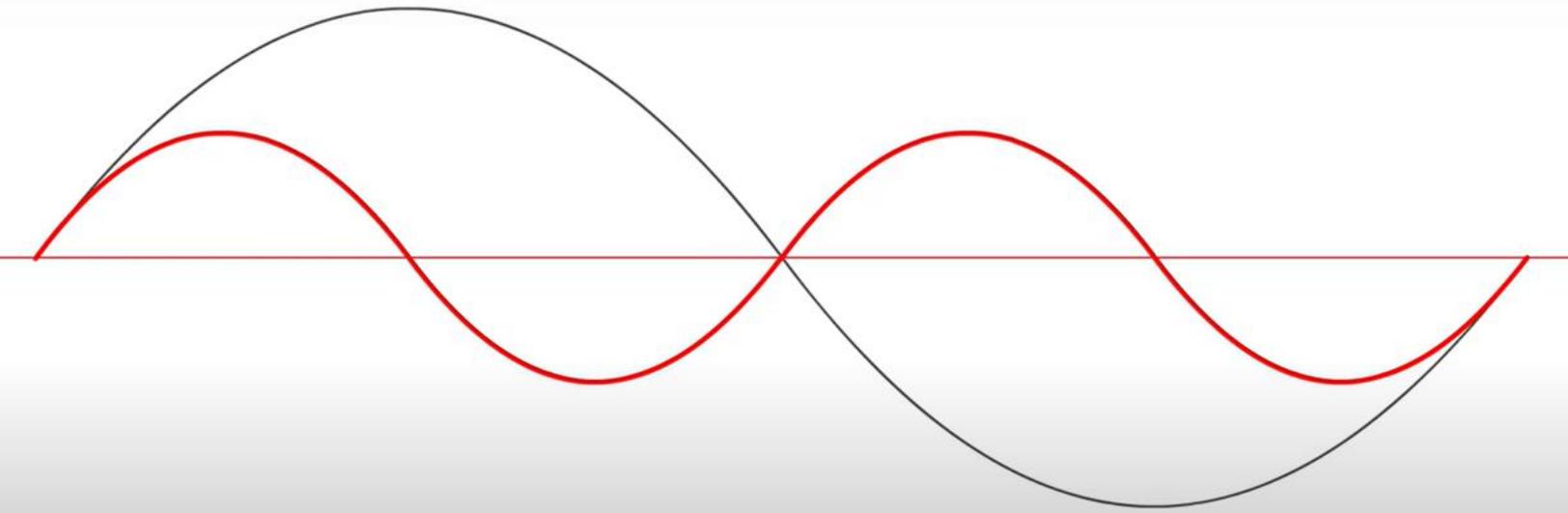
8.3.3 Backing Material & Q-factor

→ **Quality Factor is a unitless number that is inversely related to bandwidth.**

It is very important to remember in this section that the quality Q-factor is referring to the pureness of the tone or wave, NOT the quality of the image.

When a wave has a **high Q-factor**, it will have a **narrow bandwidth**. That means that there is less variation from its operating frequency.

For example, if this wave was taken as a sample from a wave with an operating frequency of 1.5 Hz. We can see that it has a 1 Hz frequency and a 2 Hz frequency. That is a VERY narrow bandwidth. This sound is mostly pure. (2-1 = 1 Hz Bandwidth).



To calculate the Q-factor for this wave we would want to use this formula:

$$Q - factor = \frac{\text{frequency}_{operating}}{\text{Bandwidth}}$$

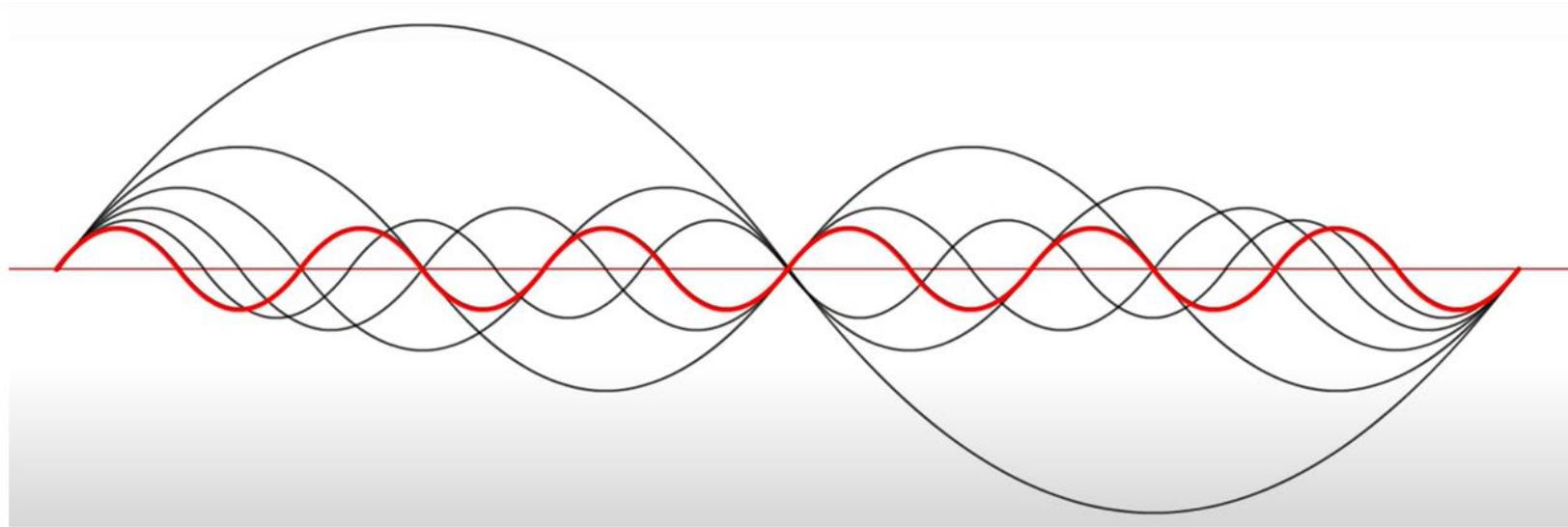
By doing so, we can calculate the Q-factor to be 1.5.

$$1.5 = \frac{1.5 \text{ Hz}}{1 \text{ Hz}}$$

The frequencies in this wave are very close to its operating frequency, meaning it is very high quality.

When a wave has a **low Q-factor**, it will have a **wide bandwidth**. That means that there is more variation from its operating frequency.

For example, if this wave was taken as a sample from a wave with an operating frequency of 3.5 Hz. We can see that it has a 1 Hz, 2, 3, 4, 5, & 6 Hz frequencies as well. That is a wide bandwidth. This sound is not pure. (6-1 = 5 Hz Bandwidth).



To calculate the Q-factor for this wave we would want to use this formula again:

$$Q - factor = \frac{\text{frequency}_{operating}}{\text{Bandwidth}}$$

By doing so, we can calculate the Q-factor to be 0.7.

$$0.7 = \frac{3.5 \text{ Hz}}{5 \text{ Hz}}$$

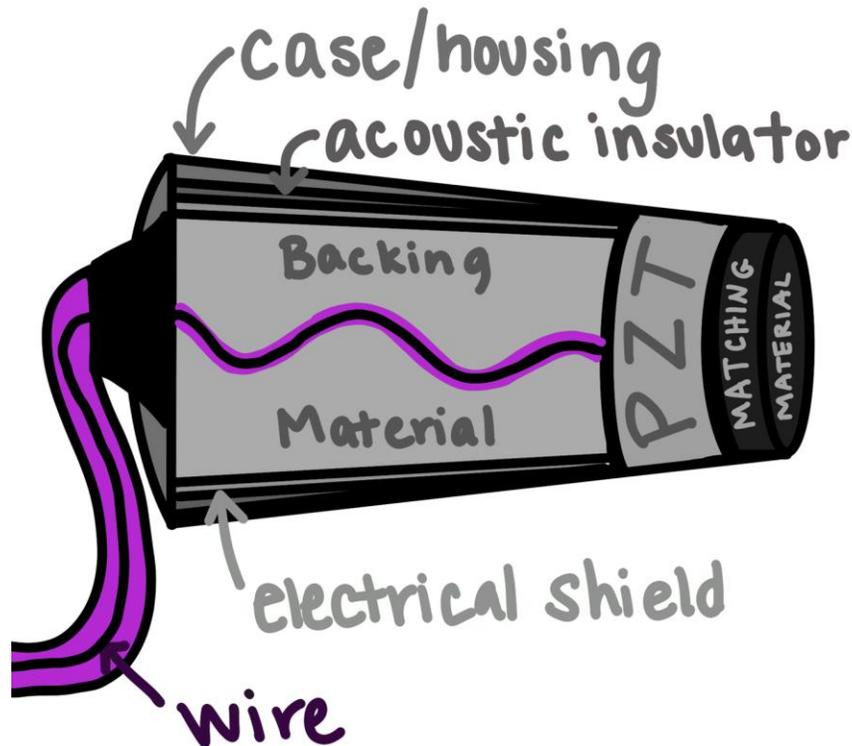
The frequencies in this wave are further from the operating frequency, meaning it has more tones to it and is lower quality.

To summarize...

The shorter, dampened pulses that come from backing material are the same ones that are more likely to have a wider bandwidth, therefore, those waves are more likely to be low Q-factor as well. All of these attributes make for the best imaging transducers, but this will be less sensitive to weak echoes.

Long waves, that have narrow bandwidths and high Q-factors are more likely to be continuous wave transducers that do not produce images, but are very sensitive to weak echoes.

Section 8.4 Wire



→ **Connects the element to the ultrasound system.**

During transmission, a voltage travels down the wire to the PZT face, which will deform the element to create the ultrasound wave.

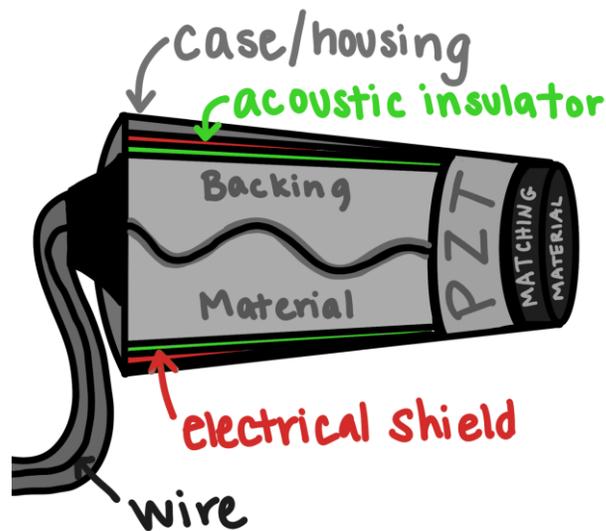
In reception, the wire will take the voltage back to the machine for processing.

→ **Every PZT element has its own wire**

The wires gather together at the base of the transducer and run through the cord. If a transducer has 250 elements, then 250 wires are running through the cord. As you'll learn in a later unit, electrical voltages will be sent down each individual wire to activate PZT elements in a very specific pattern.

It is important to take care of the wire where it attaches to the transducer and to avoid running over it with the machine.

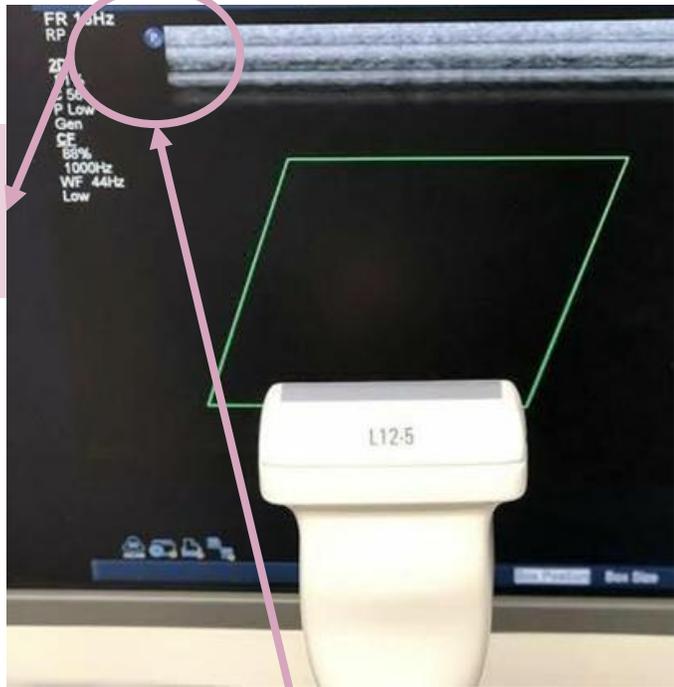
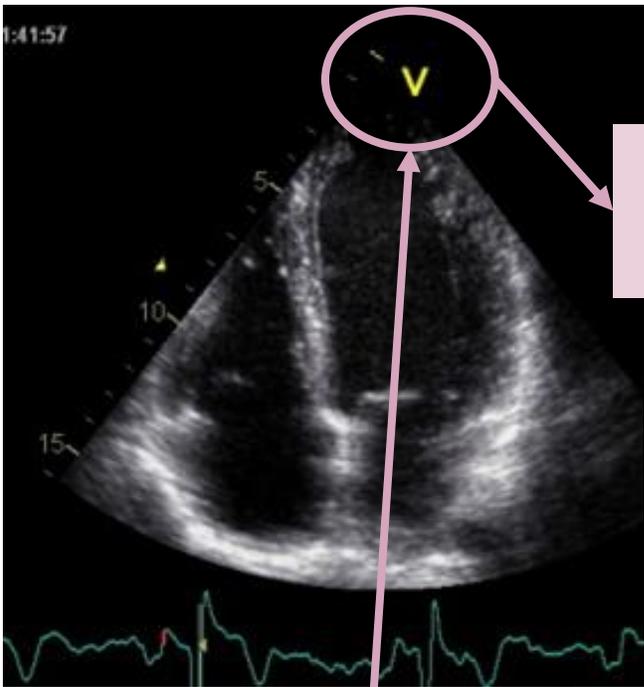
Section 8.5 Housing



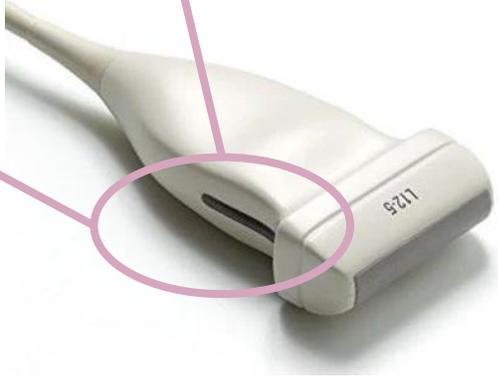
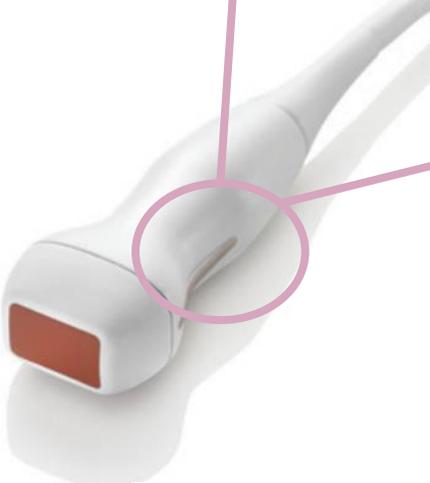
- **Case** - The outer shell of the transducer, typically made of plastic or metal.
- **Acoustic Insulator** - Thin barrier of cork or rubber meant to separate the internal components from the case and electrical shield. Stops internal vibrations from creating voltages.
- **Electrical Shield** - Metal layer under the case that keeps outside electrical interference from entering the transducer.

The outer portion of the transducer should be inspected for cracks or damage before every use. The housing will protect the sonographer and the patient from electrical shock.

The case of the transducer typically has a “notch” on the outside to indicate which side of the transducer corresponds with the imaging sector as well as other grooves that assist in connecting a biopsy kit.



Probe Orientation Marker



Notch



**Biopsy needle bracket
Philips transducer IU22**

8.5.1 Cleaning the Transducer

The transducer needs to be cleaned after every patient using a manufacturer approved wipe. This is considered low level disinfection. Transducers that are inserted into a body cavity, have been in contact with open wounds or have been used in a biopsy should undergo high level disinfection.

High level disinfection is to reduce the biological burden of microbes and viruses. Currently, fluid solutions like glutaraldehyde and ortho-phthalaldehyde are used to soak the transducer. There is also an option called a Trophon in which the transducer is steamed with hydrogen peroxide. Due to increased regulations around the fluid soaks, Trophons are gaining popularity, but they are expensive and have been known to melt the glue used to make the transducer. The transducer should be stored to avoid contamination.

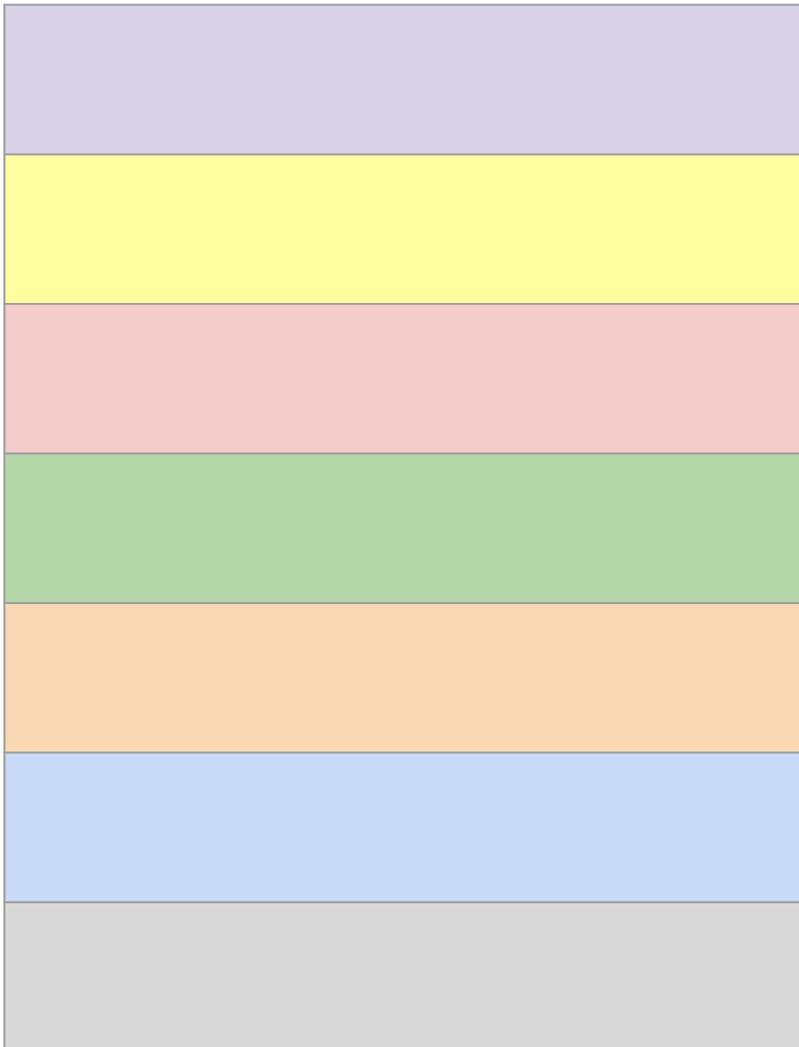
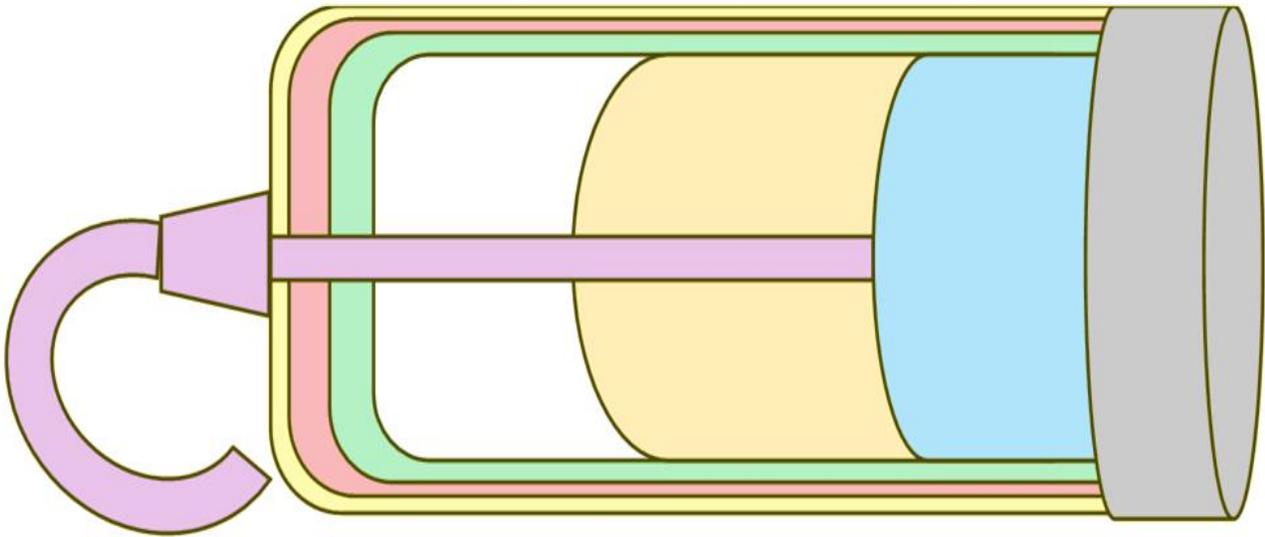
Autoclaving (sterilization) requires extremely high temperature that will melt the glue used to make the transducer and should be avoided. The concern of reaching the Curie point and eradicating the piezoelectric properties of the transducer are still low, even with autoclaving used temperatures around 250 degrees F.

Most transducers used during a sterile procedure like a biopsy or surgery are covered in a sterile probe cover and sterile coupling gel is used.



[Section 8.6 Activities](#) ← [Link to Answers](#)

1. Label the basic transducer parts.



2. Match the term to its definition.

Wire

A

Housing /
Case

B

Electrical
Shield

C

Acoustic
Insulator

D

Backing
Material

E

PZT

F

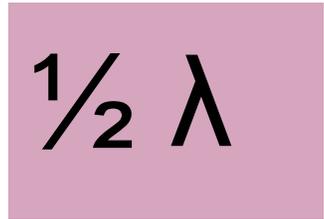
Matching
Layer

G

	Thin barrier made of cork that keeps the internal contents from causing vibrations to the PZT.
	Positioned in front of the PZT material, it protects the PZT and makes it so sound can enter the body easier.
	Brings electricity into the transducer for transmission and brings electrical information out during reception.
	Thin metal barrier that keeps outside information from entering the transducer.
	Made of plastic, holds all of the internal components, protecting the patient and user from electrical shock.
	Material that deforms to create sound waves and electricity.
	Made of epoxy and tungsten filaments, reduces ringing of the PZT to create shorter pulses.

3. Match the material to its thickness:

PZT =



Matching Layer =

4. Fill in the chart using the formulas from above.

Wavelength	4 mm		
Matching Layer Thickness		0.2 mm	
PZT Crystal Thickness			.05 mm

5. Place the items from greatest to least impedance.



PZT



Matching Layer



6. What are the three consequences of backing material?

#1	
#2	
#3	

7. TRANSDUCER A has main frequency of 6 MHz, but can emit frequencies up to 6.5 MHz and down to 5.5 Mhz.

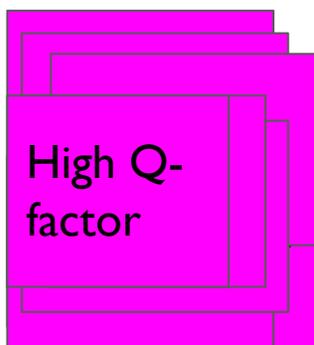
TRANSDUCER B has a main frequency of 12 MHz, but can emit frequencies up to 17 MHz and down to 5 MHz.

What is Transducer A's Bandwidth?	
What is Transducer A's Q-Factor?	
What is Transducer B's Bandwidth?	
What is Transducer B's Q-Factor?	
Which transducer is more likely used for imaging?	
Which transducer doesn't have backing material?	
Which transducer is more sensitive?	

8. Sort the qualities of each transducer:

Imaging Transducers

Non-Imaging



High Q-factor

9. Transducer A: Continuous wave transducer with a transmitter of 5 MHz

Transducer B: Pulsed wave transducer with a PZT thickness of 0.5 mm and speed of 4 mm/ μ s

Transducer C: Pulsed wave transducer with a PZT thickness of 0.5 mm and speed of 6 mm/ μ s

Transducer D: Pulsed wave transducer with a PZT thickness of 1 mm and speed of 4 mm/ μ s

Which transducer listed cannot produce images?	
What is the frequency emitted of Transducer A?	
What is the frequency emitted of Transducer B?	
What is the frequency emitted of Transducer C?	
What is the frequency emitted of Transducer D?	

10. Look back at the last slide, what did you observe?

In CW transducers, the frequency of the transmitter and sound emitted is:



When the thickness of the PZT decreased...
(transducer B & D)



When the speed of sound through the PZT decreased...
(transducer B & C)



Section 8.7 Nerd Check!

1. What is transducer in general?
2. What are some examples of transducers?
3. How would you describe an ultrasound transducer?
4. How does the US transducer convert energy?
5. What is the piezoelectric effect?
6. When does the piezoelectric effect occur in ultrasound?
7. What is the reverse piezoelectric effect?
8. When does the reverse piezoelectric effect occur in ultrasound?
9. Describe the piezoelectric effect step by step.
10. What are some natural types of piezoelectric material?
11. What is another name for piezoelectric material?
12. What are most man made piezoelectric material made of?
13. How is a PZT element made?
14. What is the Curie point?
15. What are two pitfalls of man made PZT?
16. What are some other names the PZT element goes by?
17. How many elements are needed to create 2D, pulsed wave images?
18. How many elements are needed to create continuous wave ultrasounds?
19. Describe how the PZT crystal creates a sound wave.
20. What is the acoustic frequency determined by in a continuous wave transducer?
21. What are Huygen's waves and why do they matter to pulsed wave ultrasound?
22. What is the frequency of a pulsed wave dependent on in relation to the PZT element?
23. What is the average thickness and propagation speed of clinical ultrasound transducers?
24. What is the formula for calculating the frequency of the transducer based on PZT thickness and propagation speed?
25. How are frequency and PZT thickness related?
26. How are frequency and PZT propagation speed related?
27. What is the thickness of the PZT in relation to the wavelength?
28. What are the features of a PZT with high frequencies and low frequencies?
29. What is the matching layer?
30. How many times bigger is the impedance of the element than skin?

31. What happens if there is large mismatch of impedances?
32. How thick in the matching layer compared to the wavelength?
33. Why is gel helpful?
34. What is the order from most to least impedance for sound propagation from transducer to body?
35. What is backing material?
36. What is another name for backing material?
37. What is the purpose of backing material?
38. What are some of the consequences of backing material?
39. How does backing material decrease sensitivity?
40. What is bandwidth?
41. How is bandwidth determined?
42. What is operating frequency?
43. How does a ringing bell equate to our transducer ringing?
44. Why are short pulses good?
45. What does the dampening material do to create wide bandwidths?
46. Describe a transducer that has no backing material, one with a little and one with a lot and how they would produce bandwidth and pulses?
47. What type of transducer is better for imaging?
48. What type of transducer is better for continuous wave?
49. What is Q-factor?
50. What does a high Q-factor mean?
51. What does a low Q-factor mean?
52. How is Q-factor calculated?
53. What type of q-factor is seen with imaging transducers?
54. What type of q-factor is seen with continuous transducers?
55. What is the purpose of the wire?
56. How many wires are in a transducer that has 50 elements?
57. What do the wires do in transmission?
58. What do the wire do in reception?
59. What is the case/housing of the transducer?
60. What is the acoustic insulator made of and what does it do?
61. What is the electrical shield made of and what does it do?
62. Why do we need to look for cracks in the casing?
63. What are the markings /grooves on the transducer for?
64. What do we need to do do the probe when we're done scanning?
65. How do we clean transducers?
66. Why should autoclaving be avoided?