SAWA UNIVERSITY

فيزياء الأمواج فوق الصوتية/ الكورس الاول

ACOUSTIC IMPEDANCE

Sawa University	جامعــــــــــة ســـــــــاوة الاهلية
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الجانب النظري محاضرة رقم (4)

Theoretical Lecture No. (4)

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Acoustic impedance (Z) is a measure of the resistance of the particles of the density of the medium, and the velocity of ultrasound in the medium. In other words, Acoustic impedance is the opposition of a tissue to the passage of ultrasound waves and depends on:

- Density of the medium (ρ)
- Propagation velocity of ultrasound through the medium (v)

Mathematically, the acoustic impedance (Z) of a tissue (or any material) is defined as the product of tissue density (ρ) and acoustic velocity in that tissue (v) which can be written as:

$$Z = \rho\ (kg/m3) \times v\ (m/s2)$$

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Hence, acoustic impedance is measured in kgm-2s-1. The acoustic impedance is important in

1. The determination of acoustic transmission and reflection at the boundary of two materials having different acoustic impedances.

2. The design of ultrasonic transducers.

3. Assessing absorption of sound in a medium.

The ratio of the intensity of the reflected (*Ir*) wave to the incident wave (*Ii*) at the boundary called Reflection coefficient (R). For an ultrasound wave incident perpendicularly upon an interface, the fraction R of the incident energy that is reflected is

$$R=Ir\,/Ii = (Z1-Z2\,/\,Z1+Z2)2$$

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Where Z1 and Z2 are the acoustic impedance of the first and second mediums, respectively. The fraction of the incident energy that is transmitted across an interface is described by the transmission coefficient T

$$T = 4Z1Z2 / (Z1+Z2)2$$

Obviously, T+ R =1.

The body is consisting from a range of materials, such as the air in the lungs and intestinal gas, water, blood, muscle, fat and bone. Each component of the body has characteristic impedance, which depends on the nature of this matter in it. Gases have a very low density, and therefore very low acoustic impedance as shown in table 2.3.

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A large difference in acoustic impedances of the materials on each side of the boundary is referred to as acoustic impedance mismatch. In substances with a greater impedance mismatch, there is a greater amount of energy that will be reflected at the interface or boundary between one medium and another, and a smaller amount of transmitted energy.

Table 2.3: characteristic acoustic impedance of air and water.

Substance	Characteristic acoustic impedance
Air	429 $kgm^{-2}s^{-1}$
Water	1.43×10^6 $kgm^{-2}s^{-1}$

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The contrast in the ultrasound image is generated by acoustic reflections resulting from changes in acoustic impedance (the speed of sound and density). The brightness of a structure in an ultrasound image depends on the strength of the reflection, or echo. This, in turn, depends on how much the two materials differ in terms of acoustic impedance. The amplitude ratio of the reflected to the incident pulse is related to the tissue impedance values by

$$\textbf{Reflection loss (dB)} = 20\log (Z2 - Z1) / (Z2 + Z1).$$

The greater R, the greater the degree of reflection. For example, R for a soft tissue interface, such as the liver and kidney, is 0.01, meaning that only 1% of the sound is reflected, and approximately 99% of the energy is transmitted across the interface. For the muscle/bone interface 40% is reflected, and for a soft tissue/air interface 99% is reflected.

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Even though the reflected energy is small, it is often sufficient to reveal the liver border. Because of the high value of the coefficient of ultrasound reflection (R) at an air–tissue interface, water paths and various creams and gels are used during ultrasound examinations to remove air pockets (i.e., to obtain good acoustic coupling) between the ultrasound transducer and the patient's skin. With adequate acoustic coupling, the ultrasound waves will enter the patient with little reflection at the skin surface. Similarly, strong reflection of ultrasound occurs at the boundary between the chest wall and the lungs and at the millions of air–tissue interfaces within the lungs. Because of the large impedance mismatch at these interfaces, efforts to use ultrasound as a diagnostic tool for the lungs have been unrewarding. The impedance mismatch is also high between soft tissues and bone, and the use of ultrasound to identify tissue characteristics in regions behind bone has had limited success (see figure 19).

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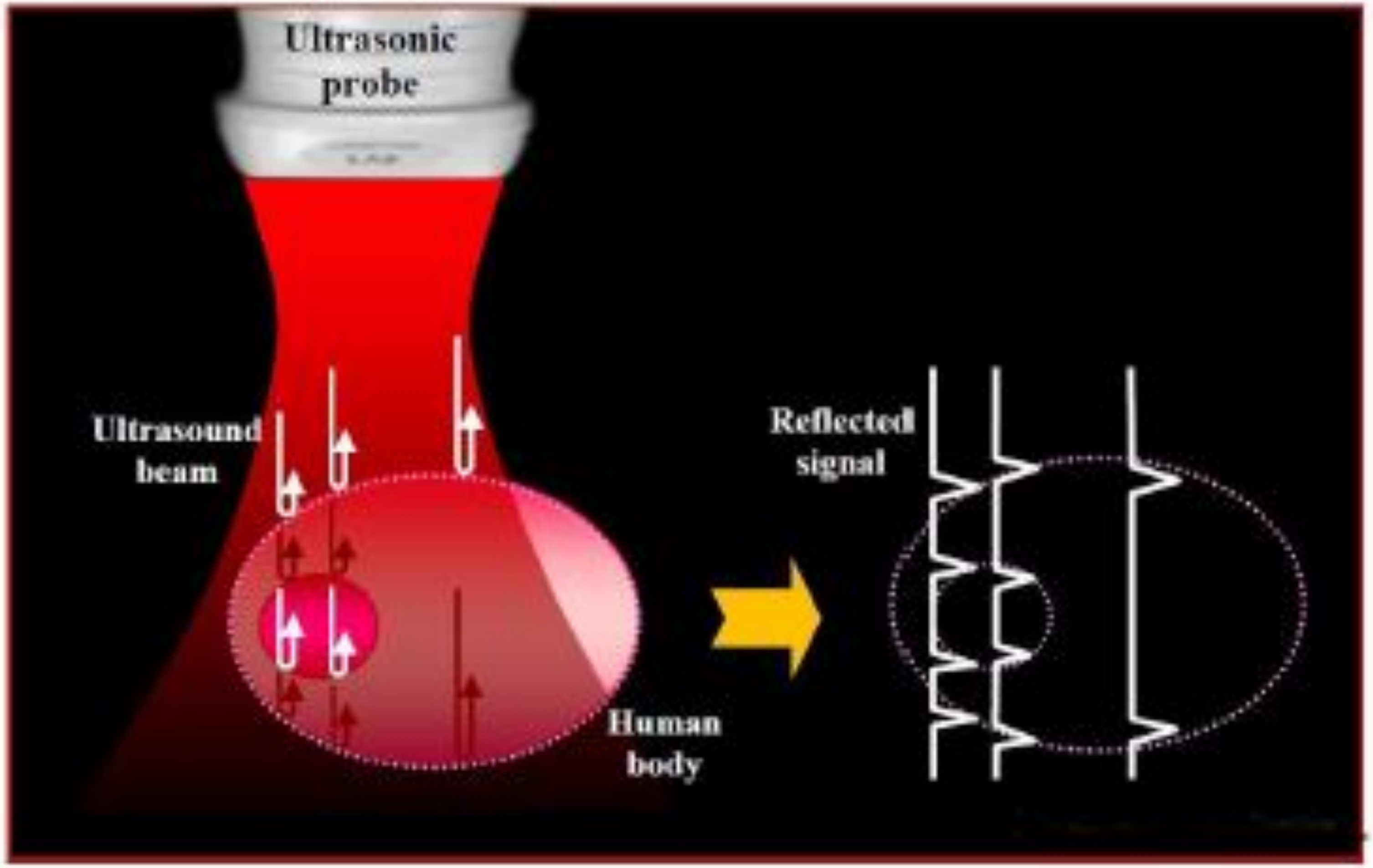

Figure 19: Reflection at a boundary between tissues.

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This is the basis of ultrasound as different organs in the body have different densities and acoustic impedance and this creates different reflectors. In some cases, the acoustic impedance can be so great that all the sound waves energy can be reflected, this happens when sound comes in contact with bone and air. This is the reason why ultrasound is not used as a primary imaging modality for bone, digestive tract and lungs.

The discussion of ultrasound reflection above assumes that the ultrasound beam strikes the reflecting interface at a right angle. In the body, ultrasound impinges upon interfaces at all angles. For any angle of incidence, the angle at which the reflected ultrasound energy leaves the interface equals the angle of incidence of the ultrasound beam; that is,

Angle of incidence = Angle of reflection

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In a typical medical examination that uses reflected ultrasound and a transducer that both transmits and detects ultrasound, very little reflected energy will be detected if the ultrasound strikes the interface at an angle more than about 3 degrees from perpendicular. A smooth reflecting interface must be essentially perpendicular to the ultrasound beam to permit visualization of the interface.

Ultrasound Contrast Agents

Ultrasound contrast agents rely on the different ways in which sound waves are reflected from interfaces between substances. This may be the surface of a small air bubble or a more complex structure. Commercially available contrast media are gas-filled microbubbles that are administered intravenously to the systemic circulation. Microbubbles have a high degree of echogenicity, which is the ability of an object to reflect the ultrasound waves.

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The echogenicity difference between the gas in the microbubbles and the soft tissue surroundings of the body is immense. Thus, ultrasonic imaging using Microbubbles contrast agents enhances the ultrasound backscatter, or reflection of the ultrasound waves (see figure 20), to produce a unique sonogram with increased contrast due to the high echogenicity difference. Contrast-enhanced ultrasound can be used to image blood perfusion in organs, measure blood flow rate in the heart and other organs, and has other applications as well. (In physiology, perfusion is the process of a body delivering blood to a capillary bed in its biological tissue. The word is derived from the French verb "perfuser" meaning to "pour over or through.")

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Figure 20: Contrast agent image.

Spatial Resolution

Spatial resolution is defined as the minimum distance between two objects that are still distinguishable. The lateral and the axial resolution must be differentiated in ultrasound images.

Lateral Resolution

Lateral resolution is the minimum separation from other tissue the ultrasound beam can see or distinguish in a plane perpendicular to the ultrasound beam (Figure 21). The lateral resolution in an ultrasound beam varies with beam width (diameter of the ultrasound beam) and the area of the focal zone. Also, it varies in the axial direction, being best in the focus zone. As many array transducers can be focused in only one plane, because the crystals are arranged in a single line, lateral resolution is particularly poor perpendicular to that plane.

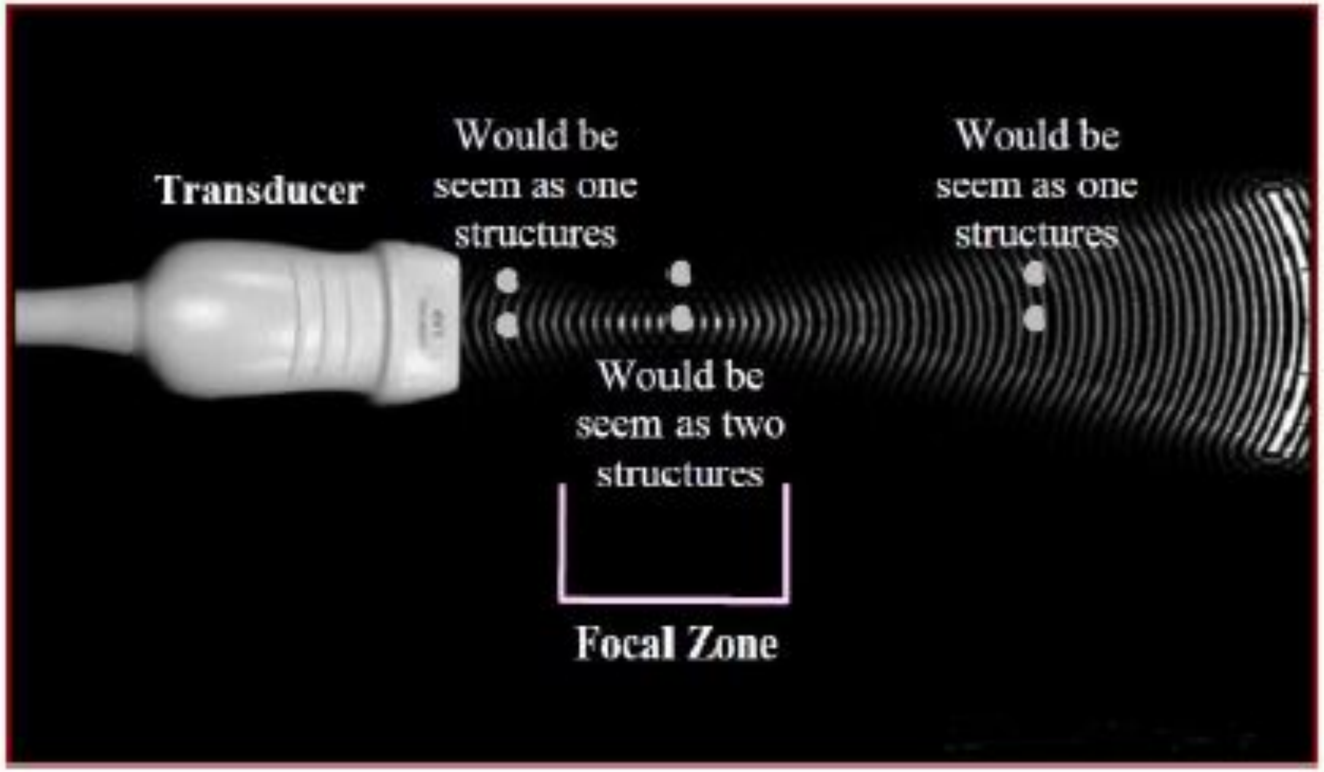

Figure 21: Lateral Resolution is the minimum separation from other tissue the ultrasound beam can distinguish in a plane perpendicular to the ultrasound beam.

Axial Resolution

The axial resolution is the minimum separation between structures the ultrasound beam can distinguish parallel to the beam path (Figure 22). Sometimes this is also called depth resolution. Axial resolution is most directly affected by the frequency of the transducer. It depends on the pulse length and improves as the length of the pulse shortens. Wide-band transducers (transducers with a high transmission bandwidth, e.g., 3–7 MHz) are suitable for emitting short pulses down to nearly one wavelength.

Modern transducers use multiple small elements to generate the ultrasound wave. If a single small element transducer is used, the waves radiate from it circularly as do ripples in a pool. If multiple small elements fire simultaneously

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However, the individual curved wave fronts combine to form a linear wave front moving perpendicularly away from the transducer face. This system, which is multiple small elements fired individually, is termed a phased array.

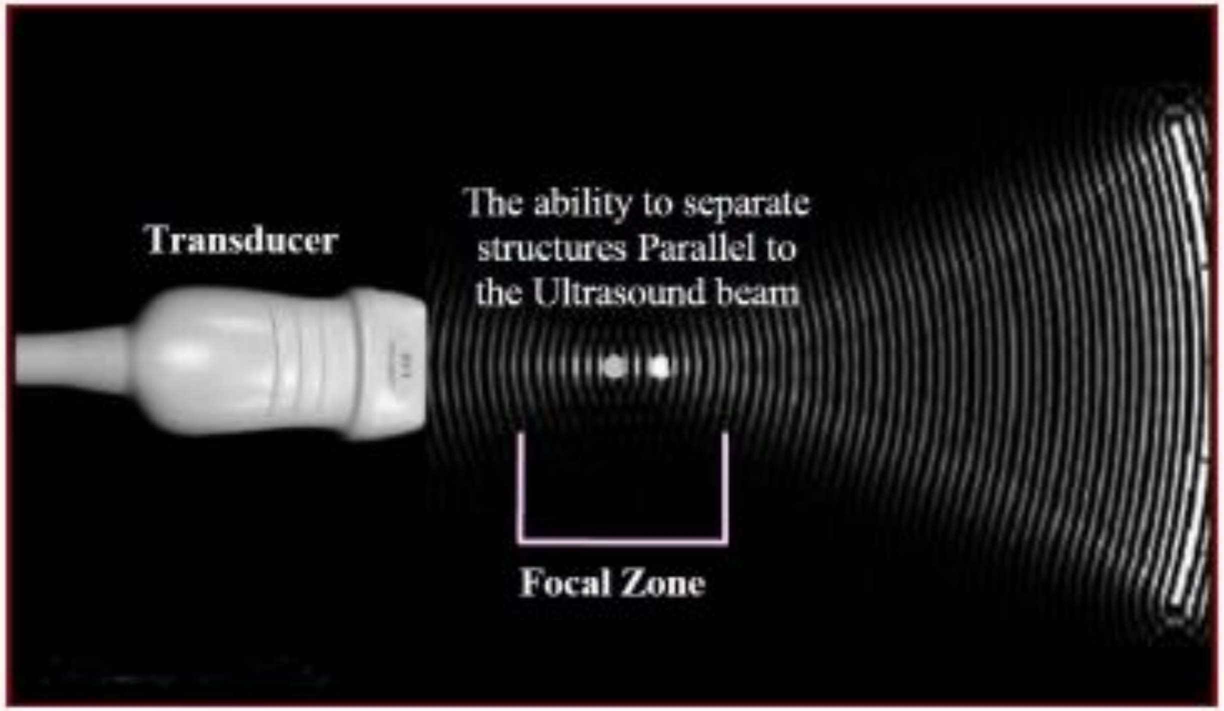

Figure 22: Axial resolution is the minimum separation between structures the ultrasound beam can distinguish parallel to the beam path.

Beam Forming and Transducers

An important characteristic of an ultrasound pulse is its diameter, which is also the width of the ultrasound beam. The diameter of a pulse changes as it moves along the beam path. The effect of pulse size on image detail will be considered in the next section. At this point we will observe the change in pulse diameter as it moves along the beam and show how it can be controlled. The diameter of the pulse is determined by the characteristics of the transducer. At the transducer surface, the diameter of the pulse is the same as the diameter of the vibrating crystal. As the pulse moves through the body, the diameter generally changes. This is determined by the focusing characteristics of the transducer.

Ultrasound Field

An important distinction is made between the near-field (called the Fresnel zone) and far field (called the Fraunhofer zone) as shown in Figure 23. The near-field is between the transducer and the focus, since the beam initially is of comparable diameter to the transducer as the series of ultrasound waves that make up the beam travel parallel to each other.

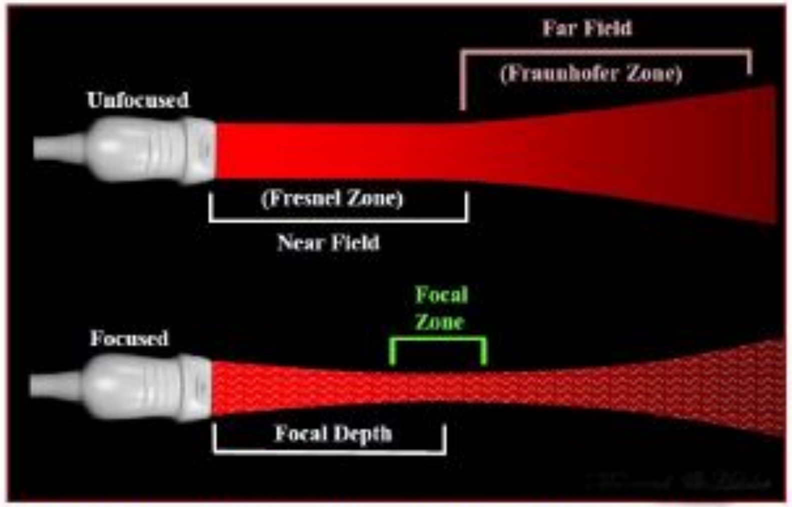

Figure 23: Beam Width and pulse diameter characteristics of both Unfocused and Focused transducers

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The far field which can be described the divergent far field beyond the focus, since at some point distal to the transducer however the beam begins to diverge which will reduce the ability to distinguish two objects close together (resolution). The border of the beam is not smooth, as the energy decreases away from its axis.

The Focal Zone is the area in the ultrasound beam that has the smallest beam diameter and is the area a user will get the best side to side (lateral) resolution.

The best detail will be obtained for structures within the focal zone. The distance between the transducer and the focal zone is the focal depth.

The focus zone is the narrowest section of the beam, defined as the section with a diameter no more than twice the transverse diameter of the beam at the actual focus. If attenuation is ignored, the focus is also the area of highest intensity. The length of the near field, the position of the focus and the divergence of the far field depend on the frequency and the diameter (or aperture) of the active surface of the transducer. In the case of a plane circular transducer of radius R, the near field length (L) is given by the expression: $Lo \sim 0.8R2/\lambda$

The divergence angle (x) of the ultrasound beam in the far field is given by the expression: $\sin x/2 \sim 0.6\ \lambda/R$. The diameter of the beam in the near field corresponds roughly to the radius of the transducer. A small aperture and a large wavelength (low frequency) lead to a short near field and greater divergence of the far field, while a larger aperture or higher frequency gives a longer near field but less divergence. The focal distance, L, as well as the diameter of the beam at the focal point, can be modified by additional focusing.

Transducer Focusing

Transducers can be designed to produce either a focused or unfocused beam. A focused beam is desirable for most imaging applications because it produces pulses with a small diameter, which in turn gives better visibility of detail in the image. Therefore, we will explain in detail the focused transducer.

It is possible to focus the ultrasound beam to cause convergence and narrowing of the beam, thus improving (lateral) resolution. Focusing can be achieved by either mechanical or electronic focusing by electronic means in a phased array element (see Figure 24).

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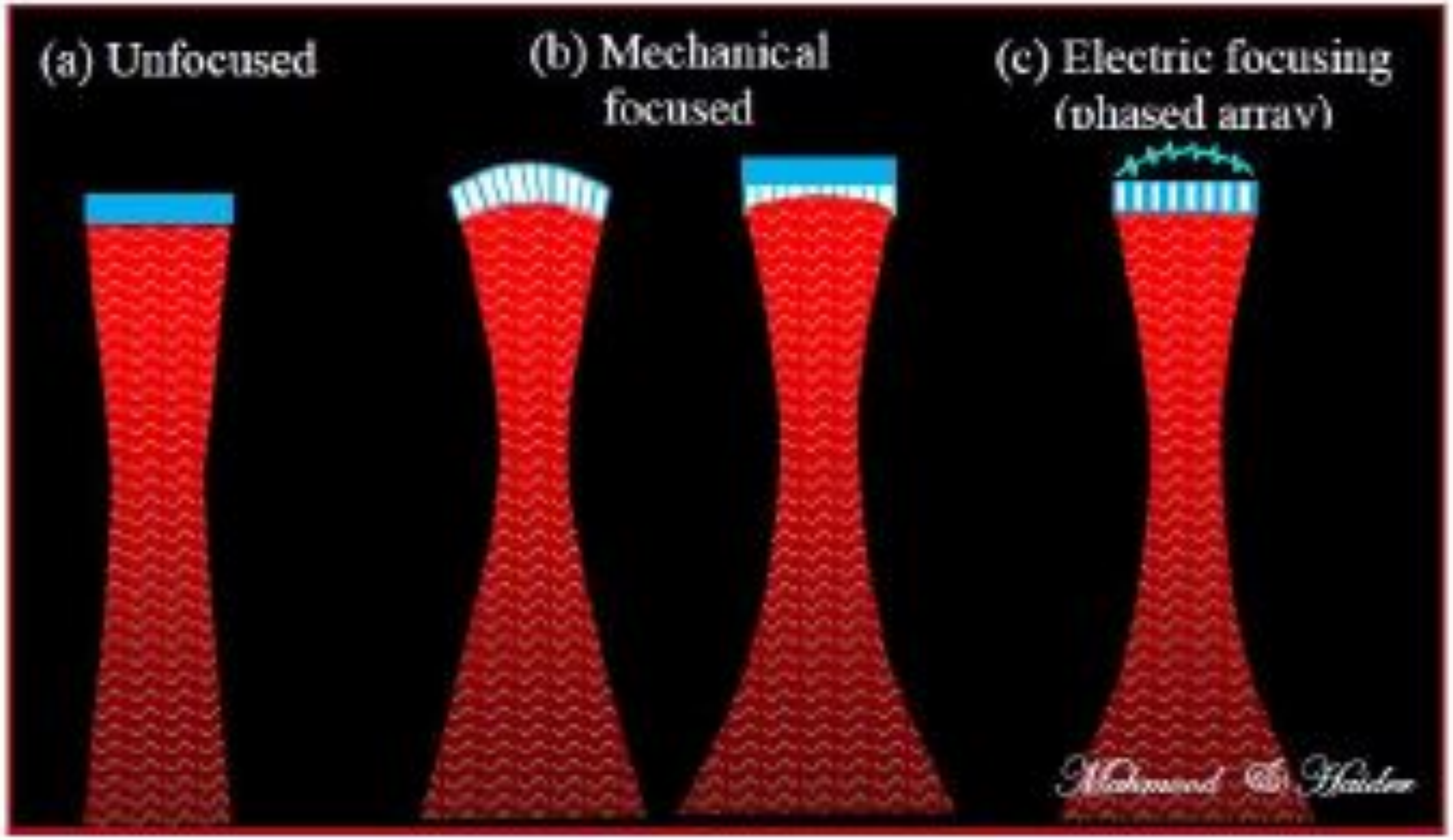

Figure 24: Design of Focused transducer

Any questions?

Thank You