ULTRASOUND PHYSICS 2025-2026

3.st Stage

Lecture 3 - Theory

ULTRASOUND IMAGING SYSTEMS

Lecturer

Amin Kadhum Awad

References: **المصادر:**

Thayalan, K., and Ramamoorthy Ravichandran. *The physics of radiology and imaging*. JP Medical Ltd, 2014.

2.8 Ultrasound Imaging Systems

The basic functional components of an ultrasound imaging system are shown below. Modern ultrasound systems use digital computer electronics to control most of the functions in the imaging process (see Figure 3). Therefore, the boxes in the illustration above represent functions performed by the computer and other electronic circuits and not individual physical components.

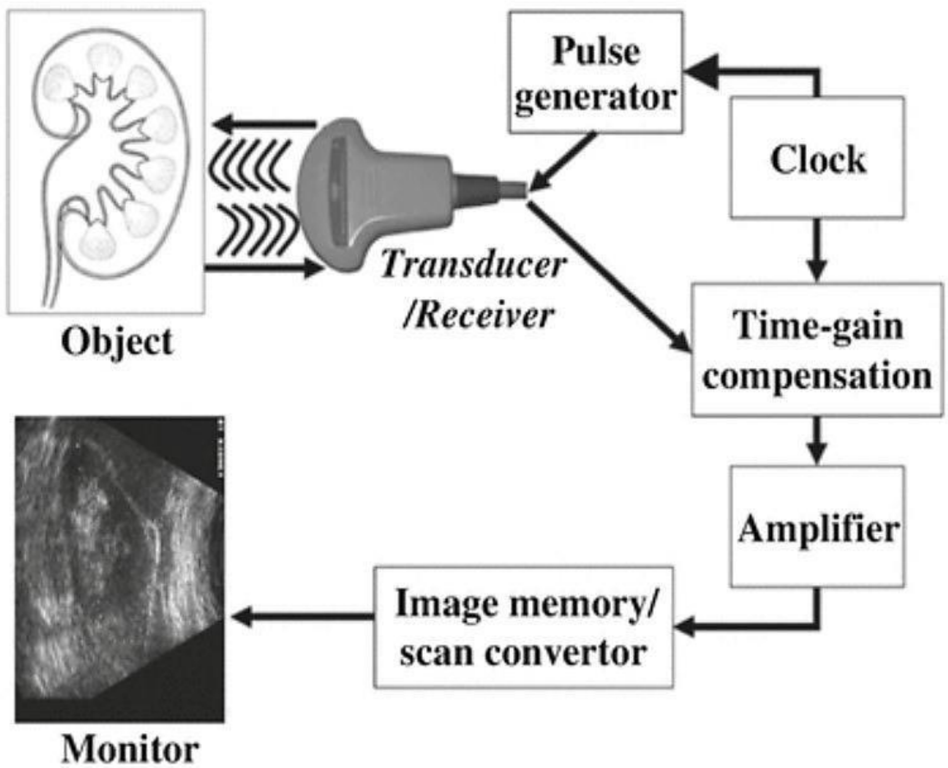

Figure 3: The principal functional components of an ultrasound imaging system

We will now consider some of these functions in more detail and how they contribute to image formation.

2.8.1 Ultrasound Transducers

In general, a transducer is a device that converts energy from one form to another, in the case of Ultrasound transducers; the conversion is from electrical to mechanical energy (or vice versa).

2.8.1.1 Ultrasonic Transducer Structures

Transducers for ultrasound imaging consist of one or more piezoelectric crystals or elements. The basic properties of ultrasound transducers (resonance, frequency response, focusing, etc.) can be illustrated in terms of single-element transducers.

However, imaging is often preformed with multiple-element “arrays” of piezoelectric crystals.

A piezoelectric transducer comprises a "crystal" sandwiched between two metal plates. When a sound wave strikes one or both of the plates, the plates vibrate. The crystal picks up this vibration, which it translates into a weak AC voltage. Therefore, an AC voltage arises between the two metal plates, with a waveform similar to that of the sound waves. Conversely, if an AC signal is applied to the plates, it causes the crystal to vibrate in sync with the signal voltage. As a result, the metal plates vibrate also, producing an acoustic disturbance.

Piezoelectric transducers are common in ultrasonic applications, such as intrusion detectors and alarms. Piezoelectric devices are employed at AF (audio frequencies) as pickups, microphones, earphones, beepers, and buzzers. In wireless applications, piezoelectricity makes it possible to use crystals and ceramics as oscillators that generate predictable and stable signals at RF (radio frequencies).

Ultrasound transducers are usually made of thin discs of an artificial ceramic perovskite material such as **PZT**. The basic design of a plain transducer is shown in Figure 4.

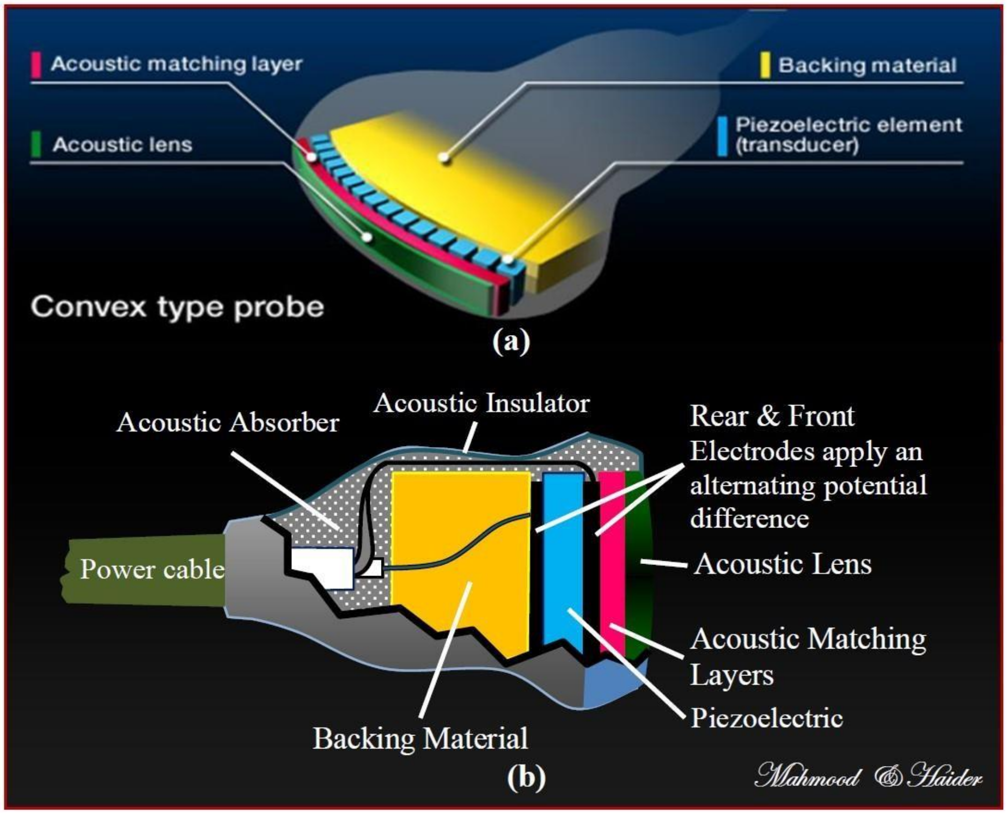

Figure 4: Basic design of (a) probe contains hundreds of transducers (b) single-element transducer.

The crystal is cut into a slice with a thickness equal to half a wavelength of the desired ultrasound frequency, as this thickness ensures most of the energy is emitted at the fundamental frequency. Generally, the thickness of thin discs (usually 0.1–1 mm) determines the ultrasound frequency. In most diagnostic applications, ultrasound is emitted in extremely short pulses as a narrow beam comparable to that of a flashlight. When not emitting a pulse (as much as 99% of the time), the same piezoelectric crystal can act as a receiver that is the transducer can act as both a transmitter and a receiver. The transducer (or probe) is containing multiple piezoelectric crystals, which are interconnected electronically and vibrating in response to the applied voltage (see figure 5). Also proved the reverse piezoelectric effect, any application of electricity to the quartz leads to vibration of quartz.

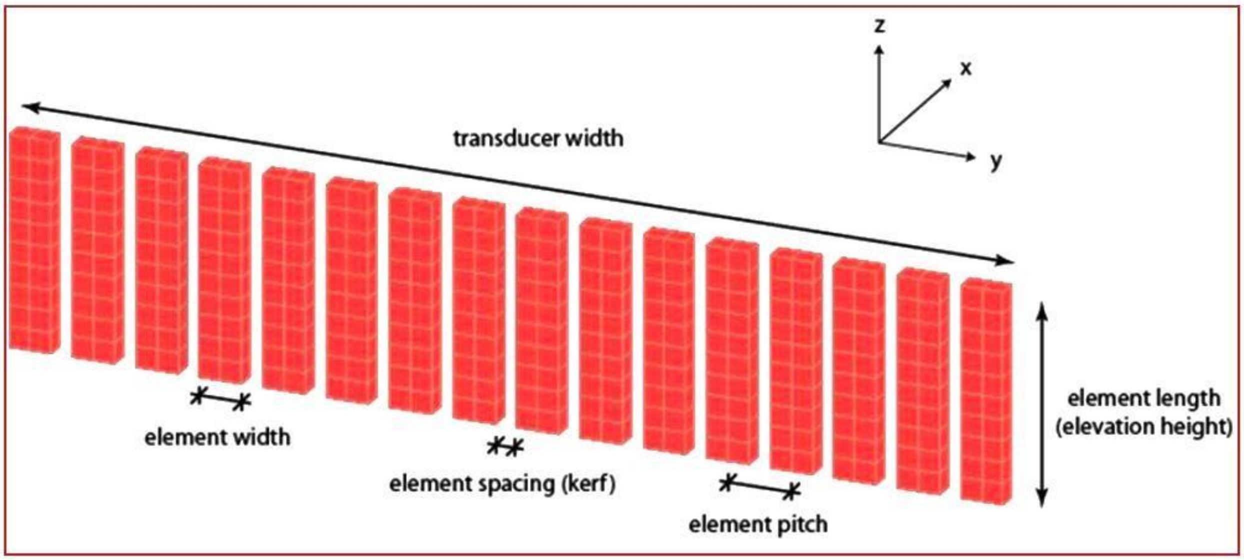

Figure 5: The transducer (or probe) is containing multiple piezoelectric crystals.

2.8.1.2 Types of Ultrasound Transducers

The essential element of each ultrasound transducer is a piezoelectric crystal, serving two major functions:

(1) **producing** ultrasound pulses.

(2) **receiving** or detecting the returning echoes.

Ultrasound systems today rely on the electro-mechanical properties of piezoelectric elements to generate the sound waves and to measure the amplitude of the reflected waves. These elements convert high voltage pulses into sound waves that travel through the relevant tissues during transmission and convert small displacements into small voltage waveforms during reception.

These devices are quite expensive to manufacture because of the various layers that must be attached to achieve the desired level of impedance matching between the device and the human skin. The Medical ultrasonic transducers (probes) come in a variety of shapes that are generally labeled according to their design or intended usage each containing a specified number of piezoelectric elements sector. That means, the ultrasound transducers differ in construction according to:

- piezoelectric crystal arrangement,
- aperture (footprint),
- operating frequency (which is directly related to the penetration depth)

There are three types of transducers are most often used in the critical ultrasound imaging:

Linear, **Sector** and **Convex** (standard or micro-convex) as shown in Figure 6.

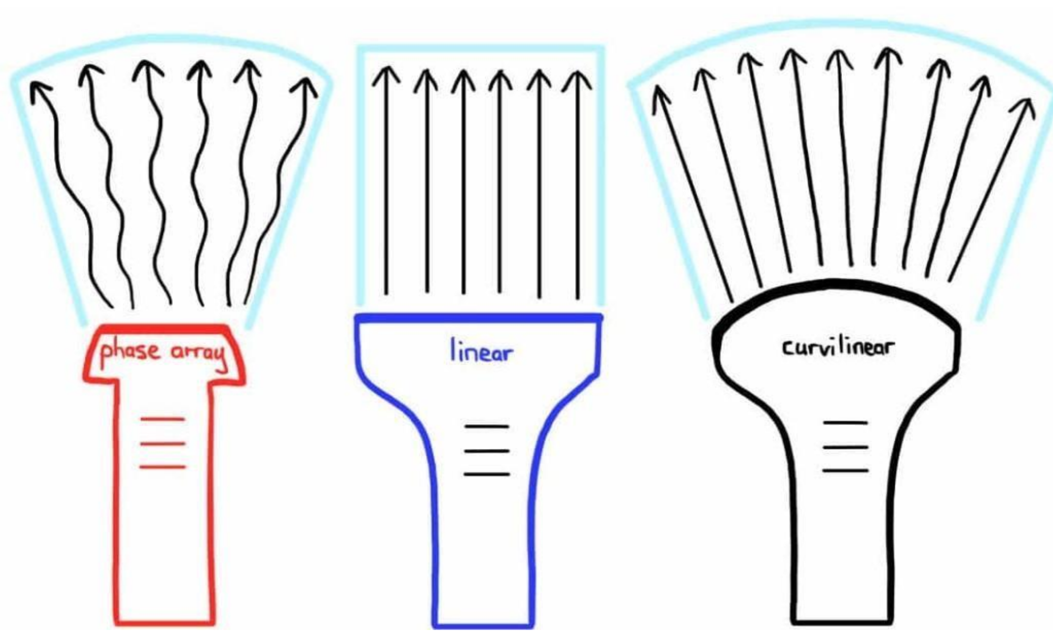

Figure.6: Three types of transducers are most often used in the clinical ultrasound imaging.

1. Linear Transducer

Linear transducers are used primarily for small parts requiring high resolution and typically involve shallow depths. To achieve high resolution, higher frequencies are typically required. Since produce a rectangular image the elements are arranged in a linear fashion.

- piezoelectric crystal arrangement: linear.
- footprint size: usually big (small for the hockey transducers).
- operating frequency (bandwidth): 3-12 MHz (usually 5-7.5 MHz).
- ultrasound beam shape: rectangular.
- use: ultrasound of the superficial structures, e.g., obstetrics ultrasound, breast or thyroid ultrasound, vascular ultrasound.

2. Sector Transducer

To broaden the field of view, sector transducers are used. These transducers have a small footprint and are good for cardio applications due to small rib spacing.

- piezoelectric crystal arrangement: phased-array (most commonly used).
- footprint size: small.
- operating frequency (bandwidth): 1-5 MHz (usually 3.5-5 MHz).
- ultrasound beam shape: sector, almost triangular.
- use: small acoustic windows, mainly echocardiography, gynecological ultrasound, upper body ultrasound.

3. Convex Transducer

For abdominal viewing, curved transducers are typically used because of resolution and penetration benefits. They allow for the maximum field of view and depth because of their large aperture. Note that any type of transducer can be phase arrayed to produce a beam of sound that can be steered and focused by the ultrasound controller.

- piezoelectric crystal arrangement: curvilinear, along the aperture.
- footprint size: big (small for the micro-convex transducers).
- operating frequency (bandwidth): 1-5 MHz (usually 3.5-5 MHz).
- ultrasound beam shape: sector; the ultrasound beam shape and size vary with distance from the transducer, that causes the lack of lateral resolution at greater depths.
- use: useful in all ultrasound types except echocardiography, typically abdominal, pelvic and lung (micro-convex transducer) ultrasound.

Also, the medical ultrasonic transducers (probes) come in a variety of shapes according to intended usage each as shown in Figure 7. The transducer may be passed over the surface of the body or inserted into a body opening such as the rectum or vagina. For example, in other words, the transducer is the component of the ultrasound system that is placed in direct contact with the patient's body. Inside the transducer contains one or more of the piezoelectric elements. It's also **focusing** the beam of pulses to give it a specific size and shape at various depths within the body and also **scans** the beam over the anatomical area that is being imaged.

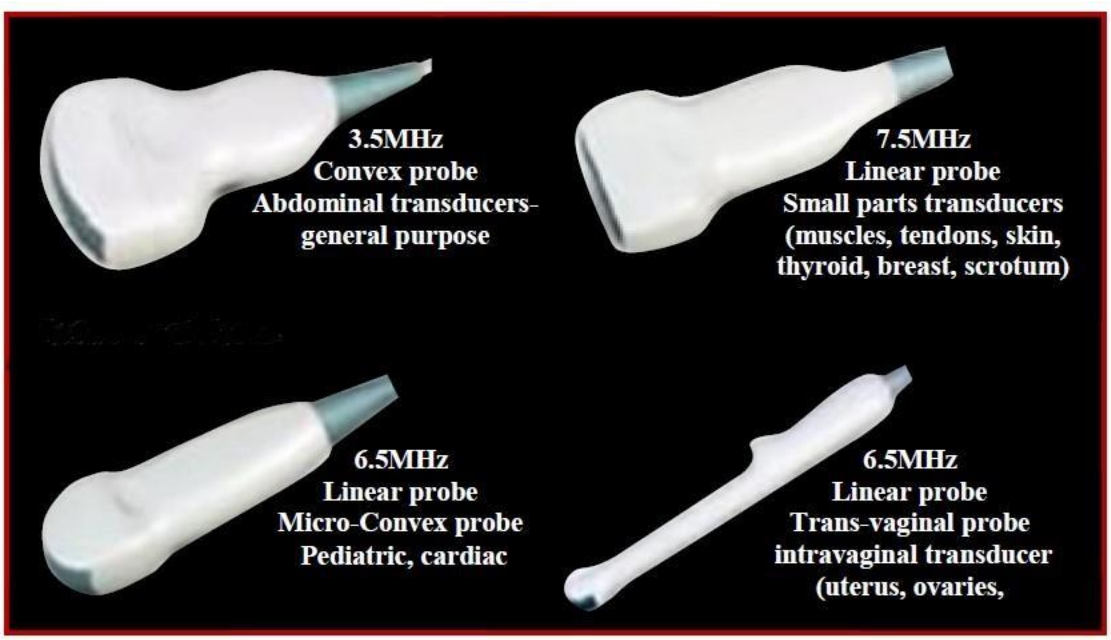

Figure 7: Ultrasound Transducer Types

Note: An ultrasound transducer is the most important and usually the most expensive element of the ultrasound machine, so it should be used carefully, which means the following:

- ✓ do not throw, drop or knock the transducer.
- ✓ do not allow to spoil the transducer`s duct.
- ✓ wipe the gel from the transducer after each use.
- ✓ do not sluice with alcohol-based confections.